SOME PAGES
TEXT FLY
WITHIN THE

Man and the Stars

A Watcher of the Skies.

MAN AND THE STARS

by

HARLAN TRUE STETSON
Director of the Perkins Observatory
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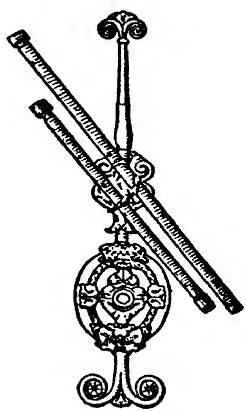

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To

G. McM. G.

In ages past, the mystic raised
His pillared temples toward the skies.
In awe of all unknown, he cringed
Before the elemental forces,
Whose mysteries he scarce dared look upon,
Save as deistic jealousies
Appeased by sacrifice.

Today man dedicates to truth
The noblest temples mind can plan,
Which rise with overarching domes
To house huge telescopes, which scan
The heavens to depths undreamed,
And send the plummet to infinity;
Exploring there to find at last
A finite universe without an end . . .

Foreword

THE mystery of the stars is, perhaps, nowhere more keenly felt than on the high seas. There, freed from the usual duties of life ashore, with sky above and sea beneath, I have written the greater part of MAN AND THE STARS.

The manuscript was begun on a return trip from an eclipse expedition to Norway in the summer of 1927. It was completed in June 1929 on a return trip from a similar expedition to Malaya.

This is in no sense a text book. Neither is it a popular guide to the heavens. It does aim to present in readable form some of the outstanding events in man's discovery of a universe of unending change, and to trace the influence of these events upon man's reactions to his environment.

The last three chapters have been included to answer questions which I have been often asked in informal gatherings after lectures. Believing that these are typical of inquiries inevitably prompted when man reflects thoughtfully upon the universe around him, I have sought to convey some viewpoints which I have often embodied in answering such questions personally.

The subject matter comprises some of the material presented for several years in courses in Astronomy in connection with the University-Extension in Cam-

bridge, Massachusetts, and represents the less technical subjects discussed in a series of lectures which I gave in 1929 as Exchange Professor from Harvard University to Carleton, Knox, and Pomona Colleges.

The rather extended emphasis on the work of some of the pioneers will, it is hoped, introduce a human touch to the romance of astronomical science, though the treatment of the characters can hardly be considered biographical.

Acknowledgment is due to Mr. Josef Johnson for reading the manuscript and proof, and to other colleagues for many helpful suggestions. To my wife, Florence Brigham Stetson, I owe more than can here be expressed, not only for attending to many details including the preparation of the index, but for the inspiration and encouragement which has made the writing a pleasure.

For permission to quote from Alfred Noyes' *Watchers of the Sky* (1922). I am indebted to the F. A. Stokes Company, Publishers, New York.

HARLAN TRUE STETSON.

PERKINS OBSERVATORY,
DELAWARE, OHIO.
October, 1930.

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Looking Skyward

At first, we bask contented in our sun
And take what daylight shows us for the truth.
Then we discover . . .

—ALFRED NOYES.

CHAPTER I

Man and the Stars

SOME ONE has said that a pessimist is a man who looks at the world with one eye closed, and that an optimist is a man who looks at the world with both eyes closed. However trite and bromidic all such definitions of the pessimist and the optimist may become they will serve to emphasize that the facts of everyday existence are capable of being rationalized in very different ways. One may read cheer or gloom, hope or despair, into the laws of nature in accordance with one's mode of reaction to his surroundings. The story of life is the story of adjustment to a changing environment. Birth, growth, age, and death are but incidents of adaptation in a whole life cycle. A drama of creation is going on in which man appears for a moment and then passes off stage. His existence on this little planet we call the earth is an event in a cosmic scheme. Just how significant this event is in the whole play we cannot tell. To view the spectacle in which we perform, to try to see ourselves as others see us has lured many a philosopher and poet to the study of nature and to reflection upon her changing moods. Some with cheerful optimism look confidently into the future of the

world. Others read a catastrophic tragedy in which man plays but the puppet's part.

The scientist sets up for himself the difficult task of being moved neither by ecstasy nor by melancholy. Whatever his personal characteristics, as a scientist he must be temperamentally nondescript. His chore is impartially to observe, record, and impart the story of events. He may use detective methods more subtle than a Sherlock Holmes in wresting the secret of creation from both rocks and stars. From star dust to fossil he critically analyzes the evidence of recorded facts and writes the story of unending change.

Science is intelligent curiosity, an organized thinking replacing a primitive wonder. That which arouses the greatest curiosity is the first to be intelligently investigated. The sky first filled men with the greatest wonder, hence the oldest of all the sciences is astronomy. As by observing others we often best come to know ourselves, so it has happened that man has learned more about the earth on which we live from a study of the stars than from the study of the earth itself. Yet it is only after we came to know the earth as a truly astronomical body that we were in any position to begin to understand the sky.

The first thing about the sky to captivate man's curiosity was not what made the stars shine, but what made them move. To identify their movement, the stars themselves had to be identified. To identify the stars called for a conscious association of one with another, the recognition of groups, the invention of configurations; hence the origin of the so-called constellations.

Few city dwellers have ever seen the stars. To feel something of the spell of the firmament one must go far from street lights and the flashing illumination of electric advertising. Starlight will not compete with the footlights of Broadway nor illuminated Main Street. Go into the country, the mountains, the desert, or venture out onto the high seas till there is nothing but the sky above and the world beneath. Then one sees the stars. Undimmed by the smoke and dust of a restless world one sees the skies as the grandest spectacle of nature. If such a spectacle were available but once in a lifetime, how crowds would throng to view the stars!

To acquire some appreciation of the meaning of the skies one must make the friendship of the stars; watch their majestic march through the night, and the slow seasonal advance of constellation after constellation from east to west throughout the year. To know Orion, Sirius, Taurus, and the Pleiades as leading roles of the winter skies; or Lyra, with its Vega, Cygnus, with its Northern Cross, Scorpio, and Antares as the quieter leaders of the softer skies of summer, gives one a sense of kinship with nature which makes a knowledge of their movements more significant, and even life a bit more worthwhile.

Excellent books on the constellations abound. Charts, maps, and even mechanical devices may be had to teach one the appearance of the sky at any hour of any night in the year. Nearly everyone knows the Great Dipper, the North Star, and the guardians of the pole, and can recognize the Galaxy—

that band of milky whiteness which sometimes dimly and sometimes brightly girdles the sky, arousing curiosity and wonder. But what is the North Star? Will the Dipper ever change its shape? What makes the Milky Way? How far away is it? These are some of the questions which have perplexed mankind from the earliest times.

To be sure, modern astronomy tells us that all the stars are suns and our sun but a rather insignificant star lost in a galactic system we call the Milky Way. Mankind dwells upon a tiny earth we call our world, and is being whirled about the sun with the swiftness of a projectile. The sun and all its planets rush through space 400,000,000 miles a year, across a universe so vast that light traveling 186,000 miles a second consumes 300,000 years in making one trip. Even more remote are other universes at distances so vast that their light takes a million years to come to earth.

Mankind did not always reason thus. Once man took the sky at its face value, for what it was to him as it met his upward gaze. The azure blue of day was but a canopy of heaven supported just beyond the horizon on some mysterious pillars of the gods. The sun itself ran its daily journey from east to west moved by the spirit of the Creator. The stars came out like street lamps lighted by the angels, to guide and guard man's ways by night.

To the ancient mind the earth was the stage on which the drama of mankind was being enacted. Thus man, occupying the center of interest, was the chief concern of creation. All else was incidental save for

the mystic powers above the veil of heaven we call the sky. Hence, in the story of creation in Genesis how casual is the reference, "the stars also." If an astronomer were rewriting the account, it might read somewhat as follows: From the beginning there have been great stellar universes each so vast that light traveling at the

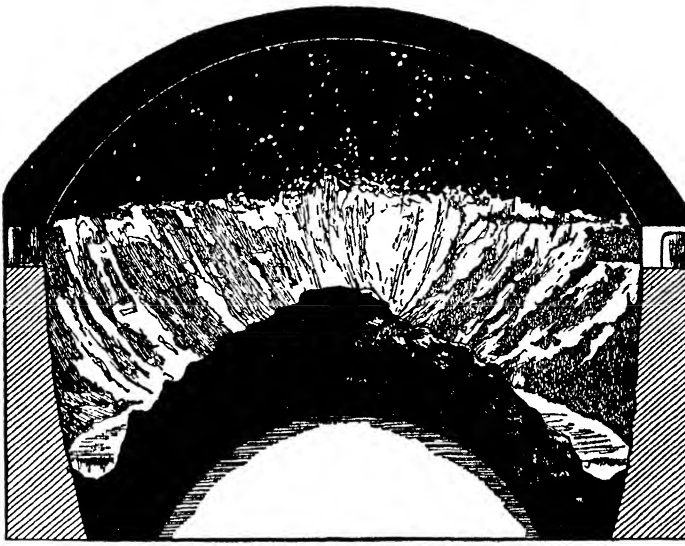

FIG. 1.—The world as conceived by the Chaldeans. *Redrawn from Mastero's "Dawn of Civilization."*

incredible speed of 186,000 miles per second takes hundreds of thousands of years to cross it. These universes stream through space at distances so remote from one another that light takes not thousands but even millions of years to pass from one to the other, so that no matter where in such a cosmic scheme one may regard himself he can never learn the true nature of things at any one time. Even were all alike and changing together, the

appearance of them would differ vastly as light from the various sources arrives sometimes early, sometimes late. These stellar universes are composed of hundreds of millions, yes billions, of gigantic, hot, gaseous bodies—the stars. One among these systems is the galactic system, composed of a billion or more of such bodies all in rapid motion. These stars differ enormously in dimension; some are so huge we call them giant stars, others so tiny we call them dwarf stars. Among these dwarf stars is the sun. About the sun whirl little planets, the largest of which is a planet called Jupiter. There are other planets—Neptune, Uranus, Saturn, Mars, Venus, and Mercury. Then there is the earth also. On the earth, as presumably on many other bodies, arise all sorts of forms of life and among the various forms of life at length comes man, who looks into star strewn space and wonders, as we wonder.

Apart from the direction of gravity which draws all things toward the centers of stars and planets, there is no such thing as up or down. Man looks, therefore, out into space and comes to find that he dwells among the stars—stars about him on every hand. He dwells upon a moving earth, spinning on its axis like a top, giving him a view into nearly every niche of space in the course of twenty-four hours. Again, he travels on a moving earth which whirls about the sun a turn a year, and earth and sun together pursue a flight through space of 40,000 miles an hour, 400,000,000 miles a year, while the passing stars are so far distant, they stream by so slowly, that centuries elapsed before man perceived their slightest drift.

Thus has man's view of the cosmos changed from his little homocentric picture of creation to a scheme so vast that were it not for his own self-consciousness he might well regard himself as out of the picture. So completely changed is the viewpoint, so utterly inconsistent with the first appearance of things, one may well inquire into the data and the processes of thinking whereby it came about. This is the story of astronomy.

CHAPTER II

The Earth in Space

NEARLY every one believes the earth is round like a ball, turns on its axis, and revolves about the sun, facts which are fundamental in interpreting the sky. Few stop to inquire why they believe these things. Few, indeed, have the remotest idea of the actual struggle of man's mind in attaining what we so glibly state for common knowledge. The conception of a round earth is certainly contrary to any intuitive deduction from the most obvious and normal observations of nature. How do you know the earth is round? Because it has been circumnavigated; because a ship sailing out of port disappears gradually, hull first, sails next, and last the tops of the masts. This is the schoolboy's answer, not usually because of personal experience or observation, but because this is what he has been taught as proof, and it is supposed to have the weight of competent authority. But does he ever stop to consider that such evidence falls far short of proving the earth is anything like spherical? In fact, would not the same statements hold equally well if the earth were shaped like a cucumber, a pear, a biscuit, or a dozen other objects whose surfaces exhibit convexity? What was it that led men to venture

upon the idea of sphericity as totally contrary to the obvious? What single observed fact taught man his first great astronomical lesson that things were not always what they seem? This—that the aspect of the sky itself changed with travel. One's ideas have always been changed by travel, and man got his first clue to the true nature of the earth as an astronomical body through travel.

A little above the southern horizon of Greece at certain seasons of the year stood the bright star, Canopus, known of old to sailors. As a guiding star it led them southward across the Mediterranean to Alexandria. As southward they steered their way, they noticed the star stood higher and higher above the horizon each night as it crossed the meridian, till at Alexandria it shone full seven degrees above the highest point it ever attained at home. When they sailed back to Rhodes it dropped again a little each night, according to the distance sailed, until it reached again its accustomed altitude in Grecian skies. This observed changed aspect in Canopus was found to be common to all the stars and was only to be explained by assuming that men traveled not on a plane but on a curved surface. Moreover, since the altitude of a star increased or decreased by an amount exactly proportional to the distance traveled, the philosopher, Eratosthenes, perceived that the curve on which men sailed must be the arc of a circle and, hence, the earth itself must be spherical in shape. By rightly measuring the length of the distance sailed from the estimated speed of the ship and the time spent in transit, he

had the length of an arc of the earth's circumference of seven degrees. From this, the entire length of 360° was computed, which gave the circumference of the earth. The diameter on the basis of this datum was grossly in error because of the crudeness of the method but, nevertheless, sufficed to demonstrate the earth's rotundity and the order of its size. Thus was established in Grecian science the fundamental idea that, like the sun and moon, the earth is round, and the foundation was laid for its conception as an astronomical body. Quite as important perhaps was the fact that the aspect of the sky could be changed by venturing to distant latitudes.

Another valid proof of the earth's rotundity is to be found from the observation of lunar eclipses. When, as occasionally happens, the moon in its journey around the earth passes into the earth's shadow, it is observed that the shape of the obscuring shadow as it encroaches upon the full lunar disk is always that of a portion of a circle. If the arc is, therefore, always the arc of a circle, one must conclude that the shape of the object casting the shadow must be circular. This, of itself, under certain conditions, would allow the earth to be shaped like a disk, cylinder, ellipsoid, or any other figure with a circular cross section. However, lunar eclipses are observed to take place with the moon in all sorts of different positions with respect to the horizon. It makes no matter whether the moon is rising, setting, or high overhead at the time of the eclipse, the form of the edge of the shadow is always circular. Eclipses, therefore, happen with the earth turned in

all sorts of positions with respect to the moon. The only shape the earth can have if it casts a circular shadow under all circumstances is a sphere. This demonstration rests upon no instruments of precision, and the force of its argument must have been felt by the earliest thinkers.

The matter of the earth's daily rotation upon its axis was not so obvious, nor indeed so easily capable of direct demonstration. The fact became accepted by induction as a hypothesis of the observed diurnal motion of the sky long before it was capable of direct demonstration. Aristotle, the master genius of Greek thought, was among the first to perceive that the apparent rotation of all celestial bodies, sun, moon and stars, about the earth could either result from the actual movement of these bodies themselves or be but the reflected motion of the earth itself, turning at the same rate but in opposite direction, that is from west to east.

The idea seemed at first abhorrent to the majority of the early philosophers, for they, not understanding rightly the laws of motion nor the forces of gravity, argued that were the earth in motion about an axis, bodies would fly from the surface of the spinning globe as a whirling top sheds raindrops. Furthermore, they reasoned very erroneously, the earth moving through the air would create a terrific wind which would blow incessantly from east to west. That the world on which man lived could actually be poised in space and spin on an axis once every twenty-four hours, so smoothly and serenely that man could not perceive

it save by the drifting of the stars, seemed utterly beyond their minds to comprehend. Indeed, one could hardly expect with the data available that they could have reasoned otherwise. Not until extensive observations on the motions of the planets led to the abandonment of the earth as the central body in the universe and the adoption of the heliocentric theory, was the reasonableness of a rotating earth fully appreciated. It was long after the acceptance of the modern planetary system that direct experiments were devised to demonstrate objectively the turning earth.

If the early scientists had had any means of determining the distance to the planets and stars which is common astronomical knowledge today, they would have had, perhaps, the most potent arguments for the rotation of the earth in lieu of a rotation of the sky. If the celestial bodies themselves revolved about the earth once every day one could readily compute the several velocities at which they must travel in order to circumnavigate the globe in twenty-four hours. In comparison to a velocity of a thousand miles per hour, which a point on the earth's equator must move to accomplish this, we find that the moon, sixty times the radius of the earth away, would have to travel approximately sixty times this velocity or 60,000 miles per hour in order to complete its journey around the earth each day. The sun, on the other hand, at a distance of 93,000,000 miles, would have to travel more than 20,000,000 miles per hour. The velocity for Saturn amounts to 200,000,000 miles per hour, or

greater even than the velocity of light. As for the stars the number of zeros becomes so great as to make the velocity utterly meaningless. Furthermore, to be consistent with the observed lock-step motion of all the stars these velocities would have to be so nicely adjusted that each and every object should complete the round of the sky and reach again the respective rising points in the east in the space of the fixed period of the day, or twenty-four hours.

It must be remembered, however, that Aristarchus, Eratosthenes, and others of the Alexandrian school, though not having available numerical values for the distances of the planets, did conclude from certain observed phenomena that the sun was many times farther away than the moon, and probably appreciated somewhat that this difficulty of velocities was quite inconsistent with any geocentric theory presupposing a fixed earth. Therefore, long before adequate proof was available, by certain intuitive reasoning, scientific men came to believe in a heliocentric hypothesis and a rotating earth.

The hypotheses of a round earth spinning on an axis, and the earth as a planet revolving in an orbit about the sun were essentially simultaneous ventures of faith—flights of a rational imagination based on slender supports so far as direct observational evidence was concerned. These were hypotheses which were inventions of the mind of genius, unbound by tradition in its habits of thought or action. They were theories branded by orthodox science as absurd and contrary to reason, which challenged the most sympathetic

adherents with problems of demonstration requiring centuries to perform. How such "absurd" hypotheses should ever have been advanced and the vindication of such ventures into the faith of science will occupy our attention in subsequent chapters.

II

Changing Concepts

I wish that old Copernicus could see
How, through his truth, that once dispelled a dream, . . .
And seemed to dwarf mankind, the spirit of man
Laid hold on law . . .
And mounting, slowly, surely, step by step,
Entered into its kingdom and its power . . .
Amidst the whirl of universal chaos.

—ALFRED NOYES.

CHAPTER III

Wandering Stars

FROM the earliest times since intelligent man has been watcher of the sky, men have been puzzled over the curious motions of certain bright objects which, because of their erratic movements in the otherwise orderly firmament, they nicknamed the "wanderers." Today we call them "planets," taking over the Greek label (πλανήτης = wanderer).

While these so-called planets all shared in the daily motion of the stars across the sky, rising in the east and setting in the west, it was early sensed that the planets, together with the sun and moon, had slow movements all their own among the starstrewn background of the sky. This slow individual motion for the moon was west to east and at such a rate as to allow of a complete circuit of the starry sphere once each month of about twenty-eight days. Any one who has watched the young crescent moon for the first few days after new moon recalls how each successive night the crescent is seen higher and higher in the western sky at sundown. When a week has elapsed sunset finds the moon a quarter around the sky, due south, with its half-illumined surface standing upright on the meridian. Another week elapses and the moon, now

on the opposite side of the sky from the sun, shows us its fully illuminated surface and rises in the east as the sun sinks in the west. We thus trace half of the planetary motion of the moon about the earth. Another fortnight and it will have caught up with the sun again. Shortly after we see once more the slender crescent in the western sunset sky. The sun too, like the moon, has a slow eastward movement of about one degree a day, completely circumnavigating the sky in just one year's time. The path the sun thus traces among the stars is called the ecliptic. The menagerie of constellations strewn along this path is the zodiac, literally, "animal circle" (in Greek, ζωδιακός; in German, *Tier-Kreis*).

Like the sun and moon, along this zodiac plod the planets passing in turn the classic configurations in the sky; Aries (ram); Taurus (bull); Gemini (twins); Cancer (crab); Leo (lion); Virgo (virgin); Libra (scales); Scorpius (scorpion); Sagittarius (archer); Capricornus (goat); Aquarius (water-carrier); Pisces (fishes). Mercury, swift messenger of the gods, completes the circuit in 88 days, Venus in 228 days, Mars in 2 years, Jupiter in 12 years, and Saturn in nearly 30 years. These were all the planets known to the ancients and, together with the sun and moon, made the sacred number seven, a number persistently dominant in the evolution of mysticism. This added a finality to their cosmology akin to religion.

Had the motions of the five planets, Mercury, Venus, Mars, Jupiter, and Saturn, been as uniform and orderly as that of the sun and moon, the story of

the struggle for a heliocentric theory would never have been written.

To understand something of the problem of the early astronomers, look at the planet Mars. The ancients were not concerned with questions of its habitability. They were greatly concerned with the question of its motion in the sky. Like sun and moon, it had its slow eastward motion about the sky, traversing the zodiac in its allotted time of 687 days. Unlike sun and moon, however, its speed along the zodiac varied widely. For some few weeks after it appeared as morning star just above the eastern horizon, scanners of the sky observed its slow eastward pursuit of the sun, as night after night the turning heavens brought the planet into view. At length, however, they noted it was slowing down. Its steadily decreasing speed soon brought it to a standstill among the zodiacal stars. Then, to their wonder and amazement, once more the planet moved, but this time backward to the west as if to outrun its neighbors to the western horizon. This retrograde or backward motion of the planet, slow at first, soon increased its speed. Was it to retrace its steps forever? Not that. Once more it retarded its gait. Then it stopped. What next? It moved again, this time eastward. With eagerness they must have watched to see if it would stop again when it had gained once more the place where it first stalled. Not so. It moved straight on quite undisturbed till nearly 2 years had elapsed, when once more it repeated the same strange spectacle. Furthermore it was noticed that at the time the planet retrograded it gained

rapidly in brightness. The middle point in its backward movement occurred when the planet was opposite the sun or "in opposition," to use the astronomical terminology. This corresponded to the planet's maximum brightness. It was easy to infer from this that the planet was then nearest the earth. What sort of celestial

FIG. 2.—A planet describes a backward loop in its journey around the sky.

mechanism could be invented to explain such complicated phenomena? This taxed the ingenuity of the greatest philosophers of the day. All the planets exhibited this same peculiarity of motion. Many strove to solve the riddle, but it is to Claudius Ptolemy of the Alexandrian school that we must look for the exposition of a cosmology that was destined to stand for 15 centuries as an explanation of observed phenomena.

Ptolemy thrived around 150 A.D. He made many notable contributions in the natural sciences and published a catalogue of a thousand stars. His *magnum opus* was the "Almagest," an encyclopedia of the knowledge of his day. Laboring naturally enough

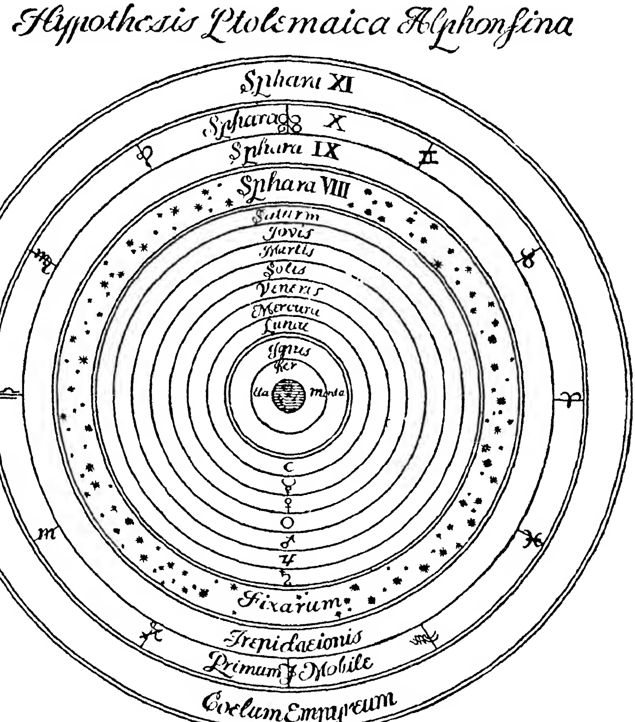

Fig. 3.—The Ptolemaic system.

under the supposition that the movements of the sky and the celestial bodies it contained found their center in the earth, Ptolemy accounted for the peculiarities of the planets by supposing each planet traveled along the circumference of a small circle, the

center of which traveled along the circumference of a larger circle at the center of which was the earth. The small circle was called the epicycle and the large circle the deferent.

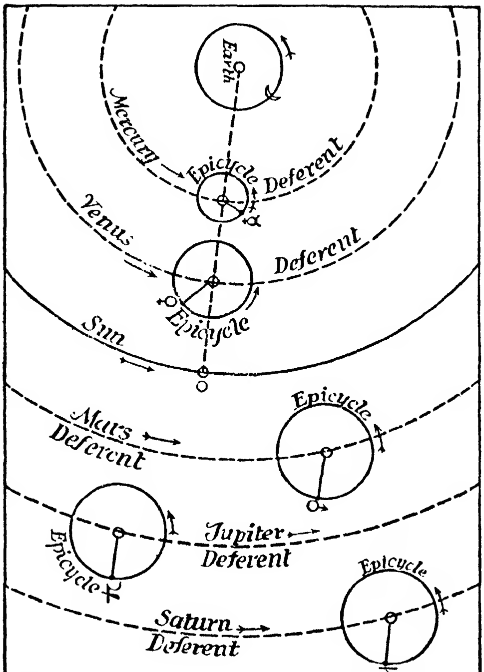

Fig. 4.—Planetary epicycles.

If we trace the path of a planet moving in accordance with such a mechanism we see that its geocentric orbit must appear much as in the diagram. The movement of the planet on the earth side of each loop will appear as seen from the earth to be retrograde or backward in the sky. The two stationary points when the planet appears to move neither east nor west will occur

at those parts in the loop when the planet is approaching or receding from the earth. The point of nearest approach must, of course, occur when the planet is shining brightest in the sky. By selecting suitable speeds and radii for the epicycles and deferents, Ptolemy was able to make satisfactory orbits for the

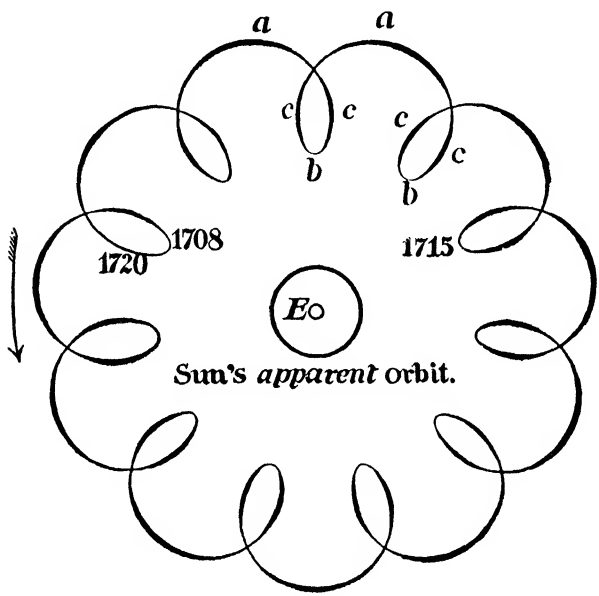

Fig. 5.—The geocentric orbit of a planet.

several planets by means of which the places of the planets in the sky could be predicted with rough approximation.

When, however, methods of measurement were improved it became apparent that Ptolemaic ingenuity must be called upon to meet new demands for adjustment of theory to observation.

As the Ptolemaic astronomers found themselves confronted with ever-increasing discrepancies between fact and theory, they decided to add more epicycles to their structure. If the epicycle worked once to solve the difficulty, why not more epicycles to solve more difficulties? So to the orbit of recalcitrant Mars was added the inevitable epicycle. Mars, they said, travels on the circumference of epicycle 2, the center of which travels along epicycle 1, the center of which travels along the deferent.

This adjustment to circumstances did very well for a time. Ere long, however, came a report from the observers that the planet was again getting off its course. Busily the astronomers puzzled themselves with new calculations, changes in speeds and sizes of the circles involved, but all in vain. By no possible combination of figures limited to the two-epicycle theory could they recapture Mars from the camp of the nonconformist.

Once again was the Ptolemaic astronomer implored for a way out of the difficulty and once again came the prompt suggestion, "Add another epicycle." Another epicycle was added. Once again, with the introduction of new arbitrary quantities their mathematical difficulties were temporarily adjusted. And the new astronomical texts of that day said that the planet Mars travels from west to east upon an epicycle 3, the center of which travels on epicycle 2, the center of which travels along the circumference of epicycle 1, the center of which travels along the deferent about the earth as a center! Years elapsed. Additional

discrepancies between planetary theory and planetary practice brought on additional epicycles, until the traffic of the sky became so congested with planets, epicycles, and deferents that King Alphonso of Spain is said to have remarked to his ardent astronomical instructor, "Sir, if I had been present at Creation I could have rendered profound advice"—a statement presumably to be interpreted less as a reflection on Deity than as a questionable compliment to Ptolemaic astronomy.

The day came when the epicycle that had nurtured the Ptolemaic theory broke its back. Like the house that Jack built, the chain of epicycles began to crumble and the elaborate structure of Ptolemaic philosophy fell, and great was the fall thereof.

CHAPTER IV

Copernicus. New Beginnings

A FITTING exponent of the breaking dawn of a new era was Nicolaus Copernicus (1473–1543). He dared face the facts of nature and of life. As a student of the stars in his monastic career at Frauenburg, he saw the hopelessness of the Ptolemaic theory and cast about for some new basis for a reconstruction of astronomy. This he found in the problem of relative motion. He was the Einstein of his day. Calling to his support certain classic references wherein Aristotle, Aristarchus, and the Pythagoreans had ventured the hypothesis of a moving earth, Copernicus launched boldly his thesis that much of the obscure motions of the planets was due to a moving earth on which men dwelt, that the earth, indeed, was itself but a planet which, rotating upon its axis, caused the apparent diurnal motion of the sky. Traveling about the sun once a year with its axis inclined to the plane of its orbit, the earth presented its northern hemisphere sometimes toward the sun and sometimes away from the sun, thus causing summer and winter, and the apparent motion of the sun along the ecliptic, that imaginary circle of the sky. With the supposition of the sun as the center of all, the new doctrine became

known as the heliocentric theory. When Copernicus applied this hypothesis of a moving earth to the motions of the planets, he was able to demonstrate readily that the curious retrograde motion of Mars and the outer planets was due to the fact that the

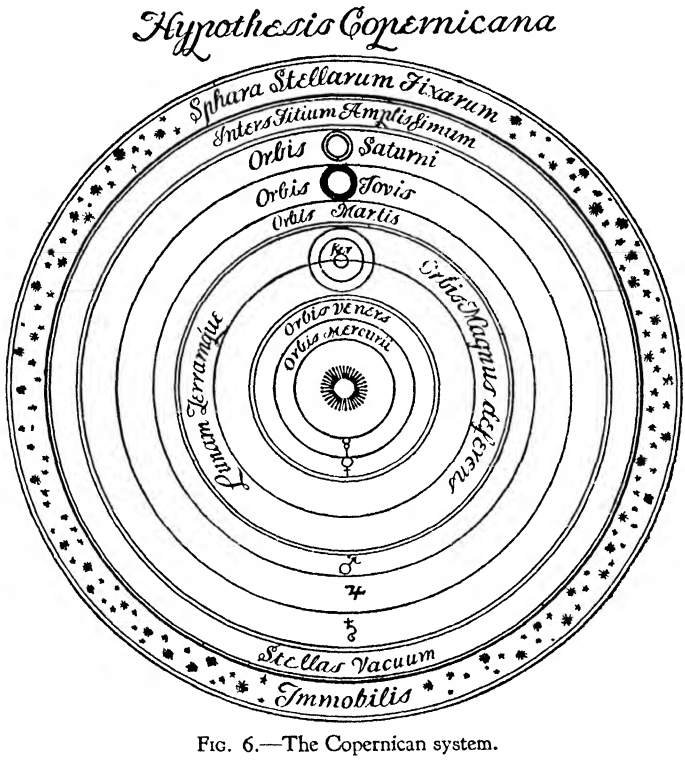

FIG. 6.—The Copernican system.

earth was the prime mover in the situation, and that the planet Mars, for example, apparently drifted backward (eastward) in the sky by virtue of the fact that the observer on the moving earth was passing by the outer planet. The earth, on such an occasion

being on the same side of the sun as Mars and traveling at a swifter pace, was actually overtaking the planet on its race course about the sun. The observer was like the passenger in a swiftly moving vehicle who

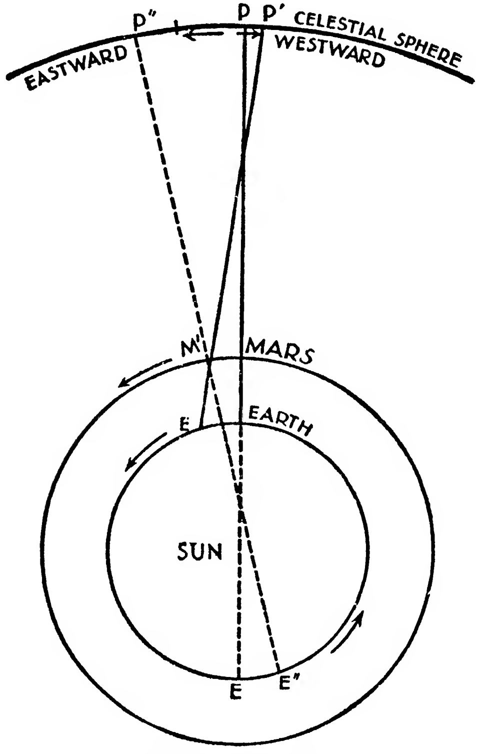

FIG. 7.—The retrograde motion of a planet.

glides by the pedestrian going in the same direction and sees him left behind with other figures of the landscape by reason of his own more rapid motion. The diagram shows this effect clearly. It will be observed that the outer planets must always retrograde

when both planets are on the same side of the sun or near the configuration called "opposition." The term "opposition" is appropriate enough when one observes that at this time the planet and the sun, being on opposite sides of the earth, will appear in opposite parts of the sky.

It will furthermore be observed that the planet then is much nearer the earth than when it is seen in line with the sun, as at conjunction. Under these circumstances the planet therefore will be brightest at opposition and while retrograding in the sky. This is exactly what happens. The reasonableness of Copernicus' argument could not fail of appreciation from those of his contemporaries capable of understanding the geometry of the situation.

Not only did the heliocentric hypothesis solve the problem of retrograde motion for the outer planets, but it was equally capable of explaining the retrograde motion of the inferior planets, Venus and Mercury. In this case the inner planet traveling the more swiftly, when between us and the sun, actually appears to retrograde by reason of its projected motion on the sky as seen from the more slowly moving earth.

If the greatest truths are the simplest, Copernicus' theory had much to commend it. With one sweeping stroke the chief function of epicycles was cast aside. Not so easily, however, were the doctrines of a geocentric theory to be deposed. That which had grown and taken root in medieval scholasticism, sacred with 1500 years of authority, was not so easily deprived of its acquired homage. Theology and ecclesiasticism which

had become inseparably entwined about a geocentric cosmology were not to acclaim so heterodoxical an idea without a long and bitter struggle. This was the dark cloud that overshadowed the horizon of the dawning day. This was what furrowed the brow of the aging curate, zealous for the truth and impatient with the inertia of men's minds.

Years passed. Copernicus lay dying. At length one day (May 24, 1543) there was brought from Nuremberg a copy of his book "De Revolutionibus Orbium Coelestium" (Concerning the Revolutions of the Celestial Spheres). Conscious that the work had actually been printed, and with a sense of satisfaction that the fruits of his work would be passed on to others, he died. Little did Copernicus know of the alteration it had suffered at the hands of Osiander, to whom he had entrusted the printing of it. Osiander, realizing the highly revolutionary character of the proposed theory, and the certain opposition that would be aroused on its publication, wrote a preface in which he declared the whole geocentric scheme was to Copernicus but an interesting hypothesis and that Copernicus had merely wished to show how, if one adopted a heliocentric geometry, the explanation of planetary motion could be greatly simplified. Perhaps Osiander was actuated by mixed motives. Possibly he felt that there was little likelihood of the book's survival unless some apologia were appended. However, it survived and caused no little consternation, whether it was regarded as hypothetical or as an exposition of truth in disguise.

One can perhaps sense Copernicus' concern in no better way than by reflection upon the words in the dedication of his work to his Holiness Pope Paul III.

I can well believe, most holy father, that certain people, when they hear of my attributing motion to the earth in these books of mine, will at once declare that such an opinion ought to be rejected. Now, my own theories do not please me so much as not to consider what others may judge of them. Accordingly, when I began to reflect upon what those persons who accept the stability of the earth, as confirmed by the opinion of many centuries, would say when I claimed that the earth moves, I hesitated for a long time as to whether I should publish that which I have written to demonstrate its motion, or whether it would not be better to follow the example of the Pythagoreans, who used to hand down the secrets of philosophy to their relatives and friends in oral form. As I well considered this, I was almost impelled to put the finished work wholly aside, through the scorn I had reason to anticipate on account of the newness and apparent contrariness to reason of my theory.

My friends, however, dissuaded me from such a course and admonished me that I ought to publish my book which had lain concealed in my possession not only nine years, but already into four times the ninth year. Not a few other distinguished and very learned men asked me to do the same thing, and told me that I ought not on account of my anxiety, to delay any longer in consecrating my work to the general service of mathematicians.

But your Holiness will perhaps not so much wonder that I have dared to bring the results of my night labors to the light of day, after having taken so much care in elaborating them, but is waiting, instead, to hear how it entered my mind to imagine that the earth moved, contrary to the accepted opinion of mathematicians—nay, almost contrary to ordinary human understanding. Therefore, I will not conceal from your Holiness that what moves me to consider another way of reckoning the motions of the heavenly bodies was nothing else than the fact that the mathematicians do

not agree with one another in their investigations. In the first place, they are so uncertain about the motions of the sun and moon that they cannot find out the length of a full year. In the second place, they apply neither the same laws of cause and effect, in determining the motions of the sun and moon and of the five planets, nor the same proofs. Some employ only concentric circles; others use eccentric and epicyclic ones with which, however, they do not fully attain the desired end. They could not even discover nor compute the main thing, namely, the form of the universe and the symmetry of its parts. It was with them as if some should, from different places, take hands, feet, head, and other parts of the body, which although very beautiful were not drawn in their proper relations, and without making them in any way correspond, should construct a monster instead of a human being.

Accordingly, when I had long reflected on this uncertainty of mathematical tradition, I took the trouble to read again the books of all the philosophers I could get hold of, to see if some one of them had not once believed that there were other motions of the heavenly bodies. First I found in Cicero that Niceties had believed in the motion of the earth. Afterwards I found in Plutarch, likewise, that some others had held the same opinion. This induced me also to begin to consider the movability of the earth, and, although the theory appeared contrary to reason, I did so because I knew that others before me had been allowed to assume rotary movements at will, in order to explain the phenomena of these celestial bodies. I was of the opinion that I, too, might be permitted to see whether by presupposing motion in the earth, more reliable conclusions than hitherto reached could not be discovered for the rotary motions of the spheres. And thus, acting on the hypothesis of the motion which, in the following book, I ascribe to the earth and by long and continued observations, I have finally discovered that if the motion of the other planets be carried over to the relation of the earth and this is made the basis for the rotation of every star, not only will the phenomena of the planets be explained thereby, but also the laws and the size of the stars; all their spheres and the heavens themselves will appear so har-

moniously connected that nothing could be changed in any part of them without confusion in the remaining parts and in the whole universe. I do not doubt that clever and learned men will agree with me if they are willing fully to comprehend and to consider the proofs which I advance in the book before us. In order, however, that both the learned and the unlearned may see that I fear no man's judgment, I wanted to dedicate these, my night labors, to your Holiness, rather than to any one else, because you, even in this remote corner of the earth where I live, are held to be the greatest in dignity of station and in love for all sciences and for mathematics, so that you, through your position and judgement, can easily suppress the bites of slanderers, although the proverb says that there is no remedy against the bite of calumny.

No sooner was the book off the press than a storm of protest arose in ecclesiastical circles as the significance of the new picture of creation began to be evident. Reconciliation with the scriptural description of creation seemed impossible. So firmly had the Ptolemaic or geocentric system of astronomy been interwoven with mediaeval theology that to dislodge the one seemed the ruin of the other.

By no means, however, was all the adverse criticism based on theological grounds. Astronomers and philosophers pointed out that if Venus went around the sun the planet should show phases like the moon. This had been told to Copernicus many times. His reply was, "Yes, I know, but God is good and perhaps some day he will show the phases of Venus to some one." We shall see later how Galileo was to be the recipient of this anticipated divine favor.

A more searching and far more critical test of Copernicus' heliocentric hypothesis was the question

of the parallax of the fixed stars among which the roving planets appear to wander. If the earth actually went around the sun on any such orbit as Copernicus postulated, critics of the new theory argued that a star should seem to shift its position slightly from season to season as a consequence of the earth's revolution about the sun. They were right. Copernicus recognized the validity of their argument. His only reply was the reply of Aristarchus, that the fixed stars were so extremely remote it had been impossible to detect their movement with any instruments then available. Thus, the heliocentric problem waited for demonstration for the more refined instruments of the nineteenth century, and it was not until 1840, nearly 300 years from the date of the publication of "De Revolutionibus," before the first parallax of a star (61 Cygni) was measured and published.

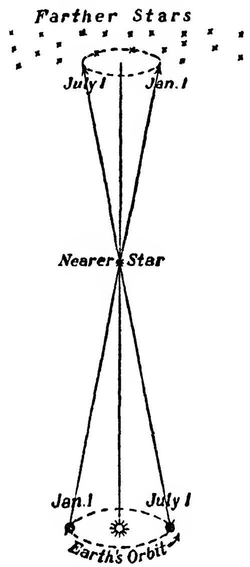

FIG. 8. The annual parallax of a star. As the earth moves in its orbit, a near star shifts its position with respect to the farther stars.

PLATE I.—Nicolaus Copernicus. (*From an old print.*)

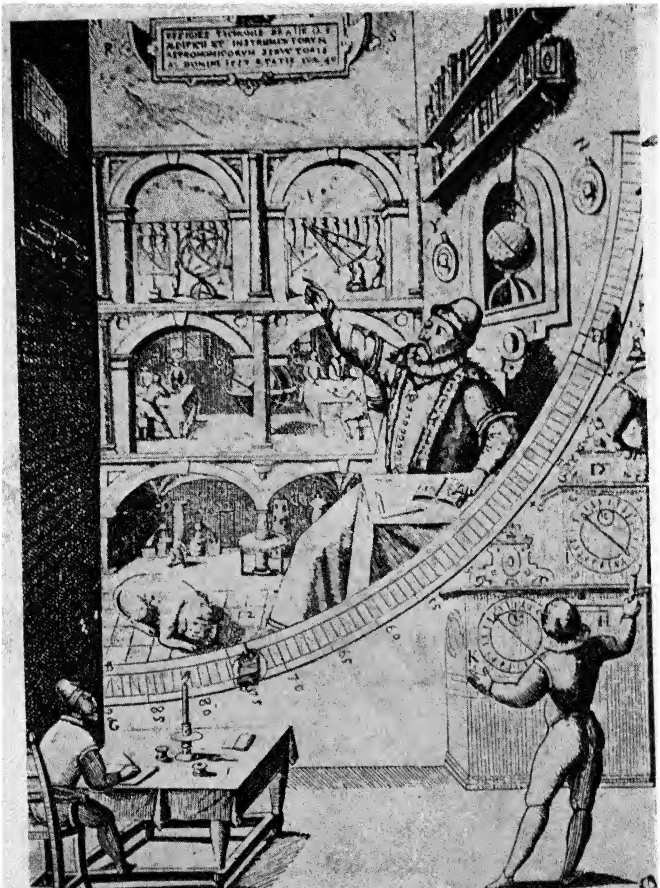

PLATE II.—Tycho Brahe and the mural quadrant in Uraniborg.

CHAPTER V

Tycho Brahe and Kepler. Explorers of the Sky

On a small island off the coast of Denmark is a mound of excavations that marks the ruins of an observatory. The island is the Isle of Hveen. The observatory had been built in the days when Denmark gloried in her Scandinavian possessions. It was the greatest temple of the stars of which the world could boast and was called Uraniborg. The bizarre edifice had been built by a curious magician, a petulant, temperamental, but ardent worshipper of the stars, Tycho Brahe.

The astronomical career of Tycho Brahe may be conveniently dated from the appearance in 1572 of a new star in the constellation of Cassiopeia. Characteristic of such phenomena it suddenly blazed forth, attained the brightness of Jupiter, attracted wide attention, and passed again into oblivion. It was soon forgotten by the world at large, but it was not forgotten by Tycho Brahe, who thereupon decided to devote himself to the study of such mysteries and to make careful records of all the happenings in the sky.

Like the new star, Tycho's inventive genius suddenly burst into the darkness of sixteenth century

ignorance and started a new epoch in the making of astronomical observations. Positions of stars and planets had been determined by early astronomers in only the crudest way. Ptolemy's star positions were not accurate within a moon-breadth. Tycho's first task was that of devising instruments that would make possible some tolerable degree of accuracy in observing the stars.

Fortunately Tycho gained favor with Frederick II, who gave him the land and funds for his instruments and observatory. Above all else the greatest contribution of this new pioneer was his improvement in astronomical instruments and method of making the observations. This made possible the fixing of the positions of the planets and stars with such precision as to provide the foundations for the discovery of the fundamental laws of planetary motion upon which the epoch-making work of Newton was the crowning achievement.

Night after night with painstaking accuracy Tycho observed the planets and endeavored to solve the problem of their motions. While a true scientist in the gathering of his data, it must be admitted that Tycho was not very hospitable to the heliocentric idea of Copernicus. Doubtless his attitude toward the Copernican theory was colored by his theological background. It must be remembered that Tycho was withal a devoted churchman. Unquestionably he felt the seriousness of displacing the earth from the center of recognized creation, whatever may have been his personal reactions to such a change. He recognized all too well the difficulty of the popular mind to so

drastic a readjustment as would be necessary were the Copernican theory accepted.

Accordingly Tycho devised a compromise theory which exhibited a deal of ingenuity as well as a temporizing tendency on the part of its inventor.

"Let us keep the earth in the center," said this Danish astronomer, "that is consistent with all our preconceived notions. Much of the advantage of the Copernican idea may still be retained if we suppose that the sun goes around the earth, and all the planets (except the earth) travel around the sun on circles of varying sizes." It is interesting to note that Tycho's inventive genius had worked out a conception which might be called a "league of planets" idea with the earth left out. It was not destined to survive long for his own observations were incapable of reconciliation with this hybrid theory.

The latter days of the noble scientist were filled with distressing circumstances. Impatient for practical results from his observatory which did not appear forthcoming, Denmark withdrew her support. Tycho was forced into exile. After cheerless wanderings, he at last settled in Prague where he gained some favor from Emperor Rudolph II.

It was while here that there came to him one day a poor student, then unknown, who was to bring the work of Tycho to a consummation of which Tycho himself had not dreamed. The youth was Johann Kepler. He was assigned the task of assisting Tycho in the computation of an elaborate set of planetary tables which came to be known as the Rudolphine

tables. The frontispiece of these tables is reproduced herewith and exhibits a curious allegorical edifice, a sort of temple of astronomy. The foundation pillars of the structure bear the names of Hipparchus, Ptolemy, Copernicus, and Tycho Brahe. The evolution

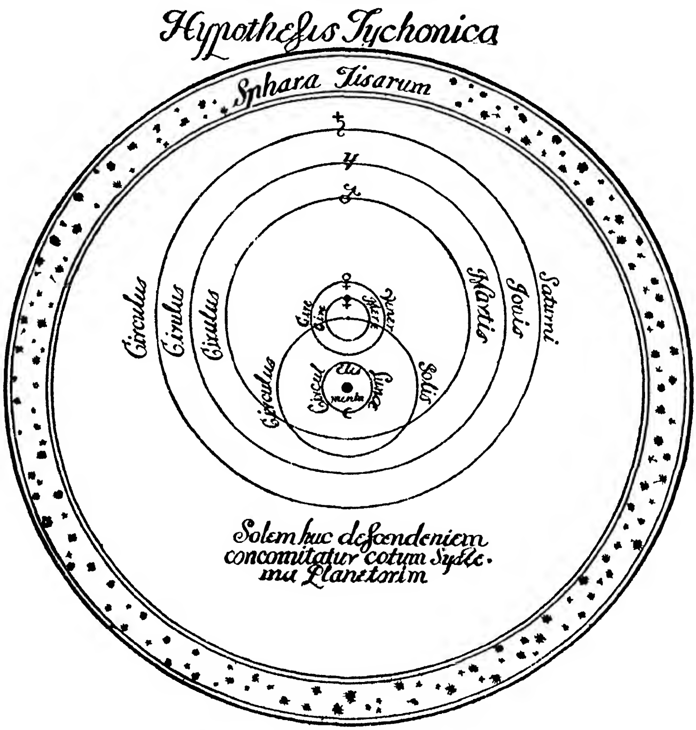

FIG. 9.—The Tychonic system.

of astronomical instruments is suggested by representative quadrants suspended here and there. In the foreground is a figure of Tycho himself pointing up to the ceiling of the structure and ejaculating "quid" as though to ask, "What is the true system of the

Plate III.—Johann Kepler.

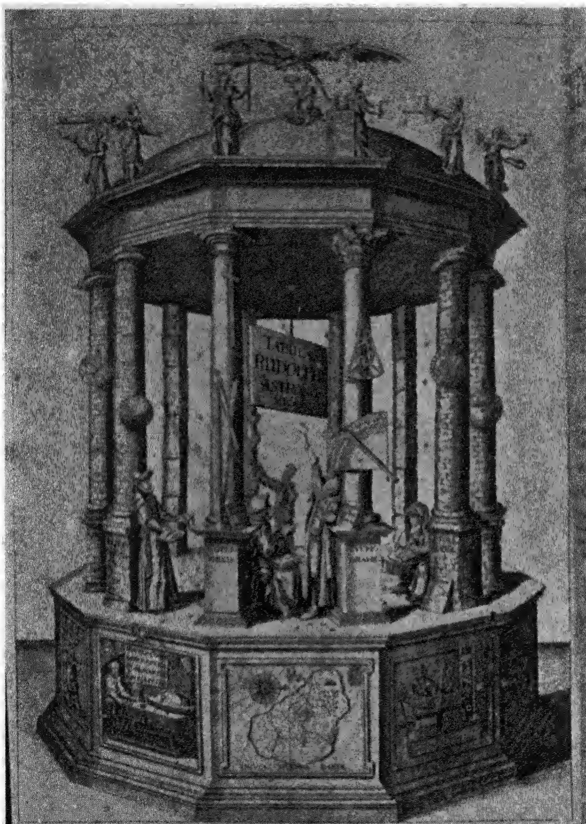

Plate IV.—Frontispiece from the Rudolphine tables.

worlds?" On the ceiling of the memorial is portrayed the Tychonic theory of the planetary system.

Acknowledgment of government aid in financing the undertaking is recognized by the Austrian eagle brooding over all and literally "coughing up" the cash to provide the endowment for the enterprise.

Along with the Rudolphine tables Kepler inherited from Tycho Brahe a strange legacy—the planet Mars! This planet because of its rapid movements had given Tycho more trouble, perhaps, than any other object in the heavens. Kepler was in no position to be concerned over the problem of the habitability of this neighboring planet as have been certain astronomers of later dates, but he was much concerned over its peculiar movements. It seemed almost impossible to discover any law or order in its strange variations of motion. The planet's observed positions fitted neither the requirements of the Ptolemaic astronomy nor that of the Copernican hypothesis. To be sure he had at one time all but reconciled its movements, when further calculation showed a discrepancy between the planet's theoretical position and its position as observed by Tycho Brahe to the amount of eight minutes of arc. This angle is almost exactly equal to that subtended by a silver dollar viewed 53 feet away! Yet Kepler reasoned that his master could not have made so big an error, and discarded the theory rather than warp the observations to fit his scheme.

After months of tedious calculation he at length began to abandon the idea of reconciling the motions of the planets with any sort of circular orbit. He came

to believe firmly that the sun was at, or near, the center of the planet's orbit but that the orbit was of some oval shape. This was a radical venture for it had become orthodox to regard the circle as the only perfect figure. To conceive that the Creator would allow planets to move in any other than circular orbits was in itself heresy.

Finally he hit upon the ellipse as a hypothetical orbit for Mars. When he placed the sun at one of the

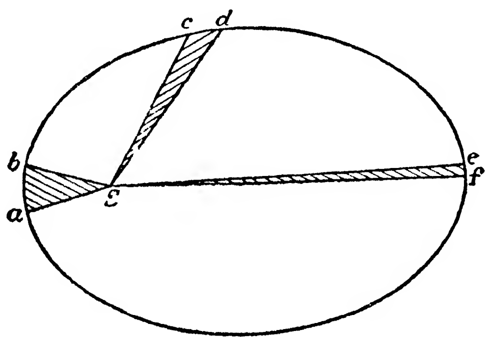

FIG. 10.—Kepler's laws. Ellipse and areas. (*Taken from Fath's Elements of Astronomy.*)

two foci of this cold mathematical figure he found all the discrepancies reconciled. Furthermore, the seemingly erratic change in speed of the planet could be described in terms of a certain generalization which has become known as the law of areas. This law states that if a line be drawn joining the sun and a planet (the radius vector of the planet) it will move over or describe equal areas each day. Thus when the planet is near the sun as at *a* it must move more rapidly than at *e* in order that the shorter radius vector shall

describe in a given time an area which is equivalent to that described when the planet is at *e* when the radius vector is relatively longer. These laws, one concerning the elliptical shape of the orbit, and the other describing the variable motion proved to hold equally well for all the planets. It remained for Kepler to disclose some inter-relation existing between the sizes of the orbits of the several planets and their relative speeds. This came only after the most arduous analysis of Tycho's tables. When he discovered the law of inter-relationship it was as music to his ears and he named it the harmonic law. To us, it sounds more like mathematics than music, but it was a strategic discovery. It may be stated thus: The square of the number of years consumed by a planet making the complete journey around the sun is equal to the cube of its distance from the sun when the distance is measured with a yard stick as long as the average distance of the sun from the earth.

These three laws stand as a monument to Johann Kepler in endeavoring to expound the "why" of planetary motion. But the explanation of them was not for Kepler to discern. That must await another mind to come, the mind of Newton.

Considering the fact that to Kepler the laws he discovered were entirely empirical, with no other reason for believing in them than that they were supported by Tycho Brahe's observations, we can but appreciate the more Kepler's notable achievement.

The accomplishments of Kepler did much to substantiate the Copernican theory, but perhaps they make an

even greater human appeal when we reflect that they were attained by a man continuously harassed by poverty and ill health. It is one of the tragedies of civilization that all too often a great genius fails of recognition by the age in which he lives, while the world heaps its honors and its wealth on lesser lights gifted with a somewhat greater degree of aggressive salesmanship for their wares.

CHAPTER VI

Galileo. Science in Conflict

One cannot intelligently gaze upon St. Peter's at Rome without recalling the master craftmanship of Michelangelo. Perhaps it is not without significance that the year in which Michelangelo died the mantel of Italian genius fell upon the cradle of a future torch bearer of science, Galileo Galilei. As St. Peter's so immortalizes art in the Italian Renaissance, so to me another cathedral in Pisa and the leaning Campanile immortalize the renaissance in science. For this Galileo was responsible.

While by no means gifted with the mathematical powers of a Kepler or a Newton, Galileo stands preeminently as the founder of experimental science. His keen powers of observation and ability of independent judgment made incompatible with his temperament the acceptance of any truth or theory on the authority of another. The preponderance of these traits marked him as distinct from any of his forebears. He was born in 1564, the son of a Florentine nobleman, and was educated at the University of Pisa for the profession of medicine. No medical career could limit the activities of Galileo's genius. While

brought up a devout Catholic, which he remained all his life, he did not let ecclesiastical exercise interfere with his enthusiasm for science. On at least one occasion during prayers in the Cathedral, Galileo's eyes wandered. He spied the swaying lamp left swinging by the verger who had lighted it. As its oscillation gradually died down, Galileo wondered if the time of one complete swing to and fro was shortening with the diminishing amplitude. Having no other timepiece at hand than the wrist-watch with which Nature had endowed him, he put his finger on his pulse and counted its beats, thus timing the movements of the suspended lamp, doubtless checking his rising enthusiasm as he carried on his experiment lest his quickening heart-throbs should alter the rate of his timepiece. To his great consternation he found that the time of swing was the same no matter how small the arc through which the lamp oscillated. He had discovered the isochronism of the pendulum, the fundamental principle upon which all precision clocks depend, and which soon led to great improvement in the manufacture of timepieces.

Galileo's deductive mind soon reasoned that the pendulum was undoubtedly far more reliable than the human pulse, so he devised an adjustable pendulum affair which came to be known as a pulsilogy. This he would carry to the bedside of his patients to measure the degree of fever with which his victims happened to be afflicted. But Galileo was becoming far more interested in experimental philosophy than he was in philosophizing about human ailments. He privately

tutored in mathematics and mechanics, and at twenty-six became professor of mathematics at the University of Pisa.

Up to the time of Galileo, Aristotle had been held as a source of all knowledge on the doings of Nature. His statements were accepted without question. His authority dominated medieval science, and if not universally regarded as infallible he was probably second to no other save the Pope. Aristotle had said that bodies fell at speeds proportional to their weights. A 10-pound body would therefore fall ten times as fast as a 1-pound body. To doubt it was heresy. To experiment to see if it was so betrayed skepticism, and was the height of impiety. But Galileo dared to doubt. A truth seeker recognizes no forbidden ground of thought. Galileo appealed to Nature. He trusted no other authority. He made his experiments. He tried bodies of various weights. They all fell at the same speed. And Galileo reasoned that could one remove the resistance offered by air, the lightest and the heaviest objects would fall side by side if dropped together. Aristotle was wrong. Galileo could contain himself no longer. He announced a public exhibition at the famous leaning tower. There he would defy the authority of Aristotle.

On the appointed day a crowd gathered at the foot of that tall slanting tower. The entire University was assembled—the wise and the ignorant, old college professors and young irresponsible students, savants schooled in medieval scholasticism and youth impatient with conventionalized theology, eager for anything

that savored of the new. Curiosity seekers rimmed the assembly.

Boldly Galileo wedged his way through the mob to the old stone doorway. With confident steps he mounted the winding stairway to the parapet above. In a few moments the eager watchers saw him emerge, make his way to the lower rim of the inclined balcony, and poise two weights upon the balustrade. One was a massive 100-pound shot, the other a pound shot. The jeers of the crowd beneath subsided as he rolled the weights to the tower's edge. Galileo looked out over Pisa not yet aroused from her medieval slumber. Confident that nature would not go back on him at this critical moment and, hiding in a jest a prayer to God, he shoved off together those two iron masses whose fall meant the downfall of medieval dogma.

Together they fell through the air. Together they plunged into the turf beneath, to the consternation of his academic colleagues and the great delight of the younger generation, then as always eager for the revolution of ideas. Infuriated with the defeat of principles to which they had devoted their lives, and envious of the enthusiasm of youth toward this new notoriety seeker, the university professors returned to their academic cloisters, climbed to the top shelf of their libraries, pulled down their Aristotle, and blowing off the dust turned to where that revered philosopher stated that bodies fall at speeds proportional to their weight. With renewed assurance they wagged their heads and affirmed, "Galileo is wrong!"

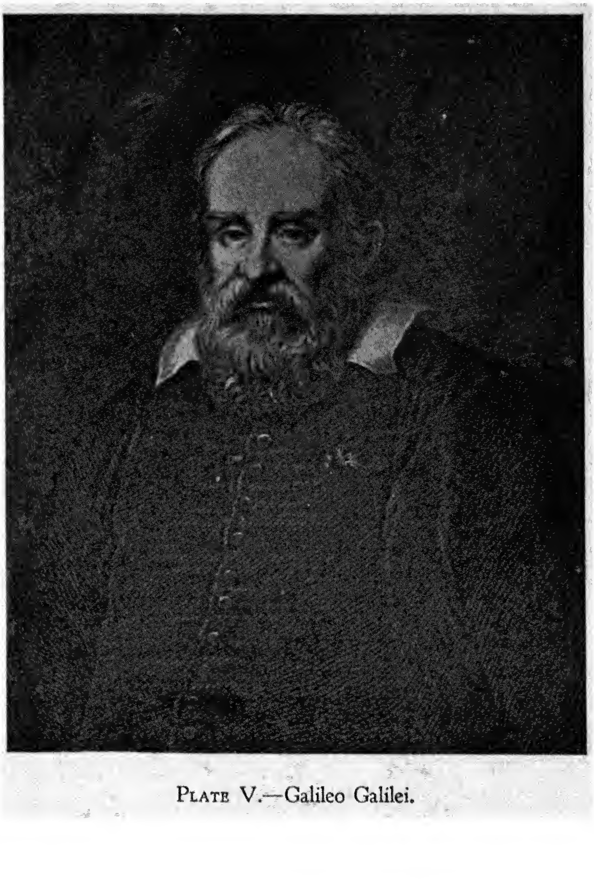

PLATE V.—Galileo Galilei.

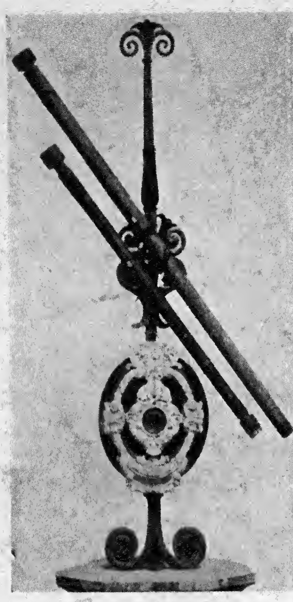

PLATE VI.—Galileo's telescopes in the museum at Florence.

Such was the power of the past over the accepted learning of Europe in the sixteenth century.

I dwell upon this incident at Pisa, not because it is so directly concerned with astronomy, but because it shows us Galileo, and so dramatically portrays the type of mind which the changing ideas of astronomy in the seventeenth century were sure to encounter. Into this era of crystallized dogma Galileo came as the exponent of creative thinking and marked for many a bitter conflict with the old régime.

Fundamental as were Galileo's researches in mechanics not only for the future of physics but for astronomy, they were hardly as spectacular or disturbing as his discoveries in the sky.

About 1609 word came to Galileo, now at Padua, concerning a magical discovery in the shop of a Dutch spectacle maker by the name of Hans Lippershey. Some apprentice had built a toy, a combination of lenses, which made the weathercock upon a distant church spire look much nearer. Galileo knew nothing of the details of the invention, but he had a fair knowledge of optics. What another could do with lenses, he could do; and this he did. Unlike the young optician, Galileo was not content to limit his gaze to the meager altitude of a weathercock, but directed his new contrivance toward the sky. With it he discovered the surface of the moon to be rough and rugged, with high mountains and deep valleys, pitted with hundreds of craters like those of extinct volcanoes, a vertible world like ours though more desolate and forbidding. Later he found that the sun, supposedly

pure and immaculate, was besmirched with spots which leisurely drifted across its surface and betrayed a globe rotating on an axis. What an argument for the doctrine of the rotating earth in the Copernican hypothesis! And what consternation such discoveries were sure to engender. On a starlit night his magic optic tube added to the sky thousands of stars unseen before. It penetrated into depths of space which the hidebound theology of Europe did not allow. But more disturbing yet, Galileo found the planet Jupiter to be

FIG. 11.—Jupiter and his satellites.

accompanied by four starlike bodies which moved to and fro from night to night. With patient vigilance he tracked their course and found that they were moons revolving about the Titan planet as our moon revolves about the planet earth. With unbounded enthusiasm, Galileo began to broadcast his discovery and openly acclaim the Copernican theory. He set his telescope where all who would might look and see the changes in the sky which it revealed. Curious spectators gazed at these celestial wonders with mingled emotions. Some refused to look lest their souls should be damned for prying into secrets the Almighty never meant for men to see!

Consternation led to opposition. Such new knowledge was sure to destroy the fabric of accepted cosmology and bring ruin to the doctrine of the church. As an illustration of the type of argument used in an attempt to discredit and refute Galileo's brilliant discovery Francisco Sizzi, a Florentine astronomer, argued thus:

> There are seven windows in the head, two nostrils, two eyes, two ears, and a mouth, so in the heavens there are two favorable stars, two unpropitious, two luminaries, and Mercury alone undecided and indifferent. From which, and many other similar phenomena of nature, such as the seven metals, etc., which it were tedious to enumerate, we gather that the number of the planets is necessarily seven.
>
> Moreover the satellites are invisible to the naked eye, and therefore can have no influence on the earth, and therefore would be useless and therefore do not exist.
>
> Beside the Jews and other ancient nations as well as modern Europeans have adopted the division of the week into seven days, and have named them from the seven planets: now if we increase the number of planets this whole system falls to the ground.

The truest part of the above statement is obviously its closing clause and nothing could be truer. Once admit the new ideas of Galileo and the whole system of medieval theology must fall to the ground.

This was the real difficulty. How to stop the advance of knowledge in light of facts was their one and serious problem. Yet to admit the truth of these new discoveries was the death sentence to age-old authority. Base denial replaced reason. Ridicule and cutting sarcasm were hurled relentlessly at those who accepted the pernicious doctrines. Father Scheiner, endeavoring

to preach an up-to-the-minute sermon, discoursed one morning from the text "Ye men of Galilei (thus playing on Galileo's surname) why stand ye gazing up into heaven." Thus, at the height of a brilliant career, forbidding clouds gathered upon the horizon.

To add fuel to the fires of opposition already started, Galileo soon announced that the planet Venus appeared through his telescope to show phases like the moon, thus fulfilling Copernicus' prophesy made a century before. According to the heliocentric theory

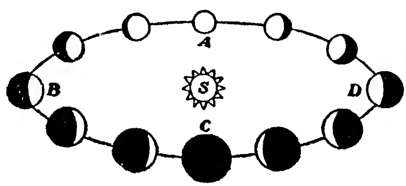

FIG. 12.—Explanation of the phases of Venus. Wher Venus is at superior conjunction, as at *A*, its fully illuminated surface is toward the earth. When at inferior conjunction, as at *C*, its dark side is toward the earth. Intermediate stages occur near elongation *B* and *D* when the planet, shining by reflected light, presents a crescent appearance.

such should be the case. Well must Galileo have recalled the words of Copernicus when admitting the lack of this demonstration to his theory he remarked: "God is good and some day he will show the phases of Venus to somebody."

The news of Galileo's discovery spread to Rome and gave no little concern, whereupon he received a special invitation to come to Rome and explain his views. While apparently he had a friendly visit with the Pope he exasperated many of the cardinals with

his tactless arguments for the heliocentric theory. It was at length decided that the Church should officially condemn the pernicious doctrine as repugnant to the scriptures and contrary to the teachings of the Holy Church. Galileo was warned against any further promulgation of the theory.

Copernicus' celebrated "De Revolutionibus," together with Kepler's treatise on planetary motions, was blacklisted and not removed from the forbidden list until the year 1835, when the books were surreptitiously dropped.

It is hard for us to realize the seriousness of the situation. No one today worries as to whether the earth goes around the sun or the sun around the earth. But to the seventeenth century minds it was a matter of life and death not only as concerned this world but, what was more important to them, as concerned the next.

To give some idea of the havoc wrought by such a heretical notion, a diagram adapted from the frontispiece of Gardner's "Dante" is reproduced herewith. In pictorial form we have the cosmology of the "Divine Comedy." This graphically portrays how astronomy and theology had become entwined to an extent that altering one meant ruin to the other.

The flat earth of Chaldean and Egyptian astronomy had given way to a round earth in the Ptolemaic system, but this was reconcilable with scripture. Progressive Biblical students had found a passage in the Book of *Isaiah* which read "He sitteth above the circle of the earth." By liberal interpretation it was

felt that this might not be inconsistent with the idea of the earth being a sphere, since a sphere would appear as a circle, as seen from above. Below the earth's surface lurked the hidden abyss with its smouldering fires and chambers of eternal torment for those who

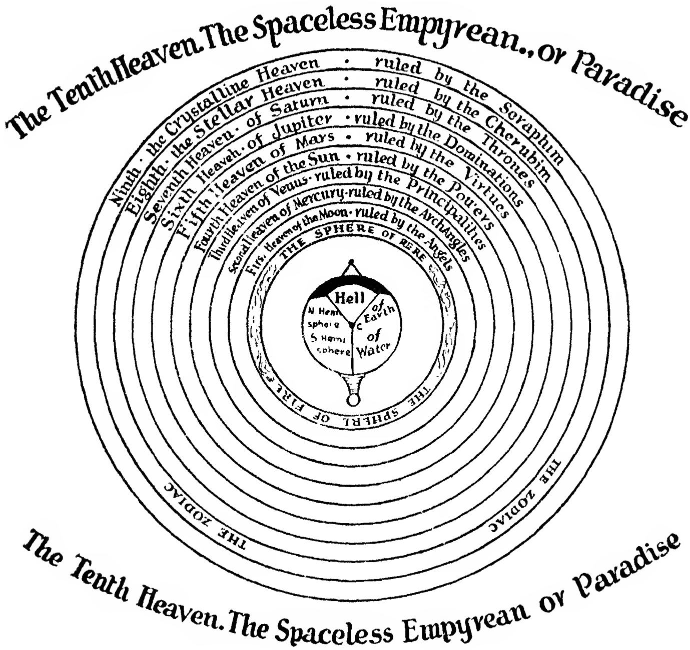

Fig. 13.—The cosmology of Dante.

did not subscribe to orthodox theology. Around the sphere of the earth was supposed to be a system of concentric transparent spheres, each ruled by one of the sacred seven planets. The first was the one ruled by the moon; the second was ruled by Mercury; then came the sphere of Venus, and next that of the

sun; and the following three were ruled by the outer planets in turn; Mars, Jupiter, and Saturn.

The eighth sphere contained the fixed stars. A ninth was the *primum mobile*. Encircling all was the tenth heaven—the Empyrean. This was an immovable boundary between creation and the outer void. Here midst a dazzling splendor sat the Triune God forever listening to the "music of the spheres" as they were rolled by specially appointed angels whose duty it was to keep the crystal spheres forever rotating about the earth.

Attendant upon the deity were three hierarchies of angels. Here were included the seraphim, the cherubim, and the thrones, whose sole occupation was to chant incessantly the divine praises.

Thus we see a complete and elaborate system of theology grown about man's primitive conception of a geocentric universe. Supported by all the proof texts from the Holy Scriptures it was deemed impregnable.

Is it any wonder that the guardians of the ecclesiastical system of the seventeenth century looked with horror upon the intrusion of a heliocentric cosmology in which the vile earth with its subterranean hell was to be placed in the fourth sphere of heaven; and the then sacred sun was to take the earth's place at the center of Creation! Like new cloth on an old garment it could not be made to fit into the old cosmological theology and they saw its doom. Is it little wonder that the elders of that day refused to look through Galileo's optic tube to see the moons of Jupiter? Is it any wonder that they indignantly contended that if

such newcomers were admitted to the sky the planets would exceed in number the seven churches of Asia and their whole system would fall to the ground?

In such an atmosphere Galileo had either to suffocate or bear the pain of conflict. Perhaps his saddest mistake was when he resigned his professorship at Padua to accept an appointment which would give him more leisure for his studies in his home country at Florence. At a most critical juncture he left Venetian soil, noted for its liberality and heterodox tendencies, for Tuscany, firm in the domination of Rome.

While Galileo seems to have kept quiet for a while, busying himself with his own studies and experiments, this quiescent period did not last long. In 1632 he published his celebrated "Dialogues on the Ptolemaic and Copernican Systems." In these dialogues Galileo carries on a three-sided conversation on the merits of the Copernican system. It appeared, however, that Salviati, the Copernican philosopher of Galileo's dialogues was consistently outwitting Simplicio, the defendant of Aristotelian philosophy. As soon as the cardinals of Rome caught the significance of this new volume, the church sought to suppress it. However, the book was widely read and the attempt at suppression, then as now, was to make the book only the more eagerly sought.

To precipitate trouble for Galileo some wag suggested to the Pope that Galileo's unfortunate Simplicio, who was getting the worst of every argument, was intended to represent none other than his Holiness, himself. Galileo's next mail from the south brought an

urgent invitation to revisit Rome. On receipt of the letter Galileo did not feel very well and was not at all enthusiastic at the idea of going to Rome again just at this time. The invitation appeared so very urgent, however, that he dared not turn it down. So to Rome he went, this time for a prolonged stay. He was not imprisoned but was scrupulously chaperoned, to use an obsolescent phrase. In the course of a few months he was summoned before the Inquisition, and his trial for heresy began. It became increasingly evident that Galileo must ultimately recant or share the fate of Giordano Bruno who had recently been burned at the stake for his unorthodox views.

This is not the place to dwell upon the ecclesiastical aspects of this tragic chapter of scientific history or to attempt to pass judgment upon the treatment of the man. I think, however, that it should be emphasized that it was not a case of the Catholic Religion against Galileo. It was the inevitable clash of new and growing concepts against an old and stereotyped mode of thinking which made no provisions for amendments to its constitution. The cardinals of Rome were faithful to their trust to save the body of truth as they saw it and it was within their province to subject Galileo to all the tortures of the Inquisition to extricate from him a denial of a doctrine in violent opposition to the accepted thinking of their day. Furthermore, the protestants were equally vehement in their philippics against Galileo for his support of the heliocentric theory. Did not the Scripture say "The earth hath He established that it shall not be moved"?

We have no direct testimony that Galileo was ever subjected to physical torture. We do know, however, that his mental agony must have been almost unbearable. Had he been an out-and-out atheist it would doubtless have been far less a strain on his constitution. On the contrary he was an ardent and devout Catholic and was continually endeavoring to reconcile his changing scientific thoughts with new interpretations of Scripture. This unquestionably made his mental conflicts the more harrowing. When at last, weakened by age and sickness he yielded to persistent urgings of his friends and did recant, I fancy it was not so much the threats of *territio realis* as the harassing torments of his own brain that resulted in his yielding to those who held at their mercy, not only the body, but the very soul of Galileo Galilei.

Whatever may be one's sympathies, the hysterical tension was relaxed when by some gesture of assent this noble man agreed to sign an abjuration.

It is a credit to an element of progressive thinking within the ecclesiastical régime that three of the ten cardinals present refused to affix their names to the text of judgment condemning Galileo—not only to the demands for abjuration but to the imprisonment for life.

The abjuration portrays dramatically the grave concern of the church over the heliocentric doctrine. It reads as follows:

The Abjuration of Galileo

I, Galileo Galilei, son of the late Vincenzo Galilei, of Florence, aged seventy years, being brought personally to judgment, and

kneeling before you Most Eminent and Most Reverend Lords Cardinals, General Inquisitors of the universal Christian republic against heretical depravity, having before my eyes the Holy Gospels, which I touch with my own hands, swear that I have always believed, and now believe, and with the help of God will in the future believe, every article which the Holy Catholic and Apostolic Church of Rome holds, teaches, and preaches. But because I have been enjoined by this Holy Office altogether to abandon the false opinion which maintains that the sun is the centre and immovable, and forbidden to hold, defend, or teach the said false doctrine in any manner, and after it hath been signified to me that the said doctrine is repugnant with the Holy Scripture. I have written and printed a book, in which I treat of the same doctrine now condemned, and adduce reasons with great force in support of the same, without giving any solution, and therefore have been judged grievously suspected of heresy; that is to say, that I held and believed that the sun is the center of the universe and is immovable, and that the earth is not the center and is movable; willing therefore, to remove from the minds of your Eminences, and of every Catholic Christian, this vehement suspicion rightfully entertained towards me, with a sincere heart and unfeigned faith, I abjure, curse, and detest the said errors and heresies, and generally every other error and sect contrary to Holy Church; and I swear that I will never more in future say or assert anything verbally, or in writing, which may give rise to a similar suspicion of me; but if I shall know any heretic, or any one suspected of heresay, that I will denounce him to this Holy Office, or to the Inquisitor or Ordinary of the place where I may be; I swear, moreover, and promise, that I will fulfill and observe fully, all the penances which have been or shall be laid on me by this Holy Office. But if it shall happen that I violate any of my said promises, oaths, and protestations (which God avert!), I subject myself to all the pains and punishments which have been decreed and promulgated by the sacred canons, and other general and particular constitutions against delinquents of this description. So may God help me, and His Holy Gospels which I touch with

my own hands. I, the above-named Galileo Galilei, have abjured, sworn, promised, and bound myself as above, and in witness thereof with my own hand have subscribed this present writing of my abjuration, which I have recited word for word. At Rome, in the Convent of Minerva, 22nd June, 1633. I, Galileo Galilei, have abjured as above with my own hand.

To look with amusement upon this seventeenth century ordeal is to fail to appreciate the real seriousness of the situation; a situation so serious as to threaten to thwart the advance of science, and to make impossible the intellectual readjustments demanded by the discoveries already made. We may laugh at the stubbornness of closed minds but would do well to look to our own times before condemning the narrow-mindedness of the Dark Ages. When Tennessee can stage a Scopes trial in the year 1926, and whole commonwealths pass anti-evolution bills in the legislatures, we may do well to appraise our own enlightenment before condemning too harshly the acts of medieval ecclesiasticism. If three centuries could elapse from the date of publication of Copernicus' "De Revolutionibus" before it was removed from the list of forbidden books, perhaps we can hardly hope the theme of Darwin's "Origin of Species" to become universally accepted in three-quarters of a century!

While for a time it appeared that science and the new astronomy had been defeated, it was only for a time. Truth once uncovered can never be permanently downed. As though in protest to the treatment of Galileo, in the very year of Galileo's death Isaac Newton was born.

CHAPTER VII

Newton. The Triumphs of Genius

THE story of Newton's career makes fascinating biography. To continue the story of the development of astronomical thinking, however, we pass the secondary events of his life to repicture the status of astronomy at the beginning of his professional career. By so doing we shall appreciate more generously the contributions of his predecessors and at the same time the extraordinary power of Newton in divining their significance for his own major problem of gravitation.

The contributions of Tycho Brahe and Kepler, resulting in the laws of planetary motion, and the subsequent revelations of Galileo's telescope had made the old Ptolemaic theory, with its earth-centered system, untenable. The Copernican idea had come to stay in the minds of true scientific thinkers. No inquisitional judgments could deny the facts. To be sure, observations had not yet disclosed that small motion of the stars in little parallactic orbits which should betray the earth actually moving about the sun, though it had been sought for. To conceive of the earth as traveling about the sun in an enormous orbit and yet to be unable to detect the slightest displacement of the fixed stars as viewed from widely different

parts of the earth's orbit was a serious obstacle to many conservative minds. The only explanation for the failure to discover this must be that the stars were at inconceivable distances from us. Further direct attack upon this problem would be fruitless until vast improvements could be made in the precision of astronomical instruments.

The laws of Kepler governing the planetary motions demanded that the planets should go around the sun and that their speeds of motion should be such that the radius vector of every planet should describe equal areas in equal times. Moreover the form of the orbits was elliptical, not circular, and the squares of the times of their revolution were mathematically proportional to the cubes of their mean distances from the sun.

All this was known to Newton, but why the planets so performed was as much a mystery as ever. What kept the planets moving? This had been the persistent problem. Thanks to Galileo's researches in mechanics a new idea in regard to motion existed. If a body was once set in motion in free space, thought Galileo, would it not go on moving forever unless something stopped it? If it did stop then some force, some friction, some retarding influence must be stopping it. In other words was not motion just as "natural" a state for matter as "rest"? Galileo believed such to be the case and he seems to have been the first to have rightly conceived of the idea of inertia. Further investigation led Galileo to believe that if a body was in motion and undisturbed it would continue at a con-

stant speed in a fixed direction. If the speed or direction changed then some force must be acting, and the change of speed or of direction of the moving body was a measure of the force acting. Thus, a falling body approached the earth at an ever-increasing speed which showed that the earth exerted a constant force or pull upon a falling body drawing it to itself. As to the cause or nature of this force he had no notion.

However much more spectacular Galileo's astronomical discoveries may have been, these fundamental contributions on mechanics were by far his greatest achievements and it was on these as a foundation that the great work of Newton was to be built. Without the recognition of these no adequate theory of planetary motion could possibly be established.

Newton's first great work, therefore, was to complete a study of Galileo's mechanics and to formulate more concisely his ideas of force and inertia. This resulted in the statement of three laws which have come to be known as Newton's laws of motion:

1. *The law of inertia:* A body at rest will remain at rest or if in motion will continue in uniform motion in a straight line unless acted upon by force.

2. *The law of force:* If change in motion exists the change will be proportional to the force acting and will take place in the direction in which the force acts.

3. *The law of reaction:* To every action there is an equal and opposite reaction.

From a consideration of the first of these laws, Newton conceived that the planets did not travel

in straight lines but in curved paths about the sun because some force must be acting continuously upon them directing them inward from a straight-line course. Upon the hypothesis of a central force directed toward the sun, Newton was able to show as a proposition in geometry that a line joining a planet and the sun must move over equal areas in equal times. This was his first triumph. He had demonstrated Kepler's law of areas merely on the supposition of a central force directed toward the sun. There remained to determine what was the nature of the force. How did it vary, if at all, with increasing distance from the sun?

Huyghens who was a contemporary of Newton appears to have worked out rather completely the laws of centrifugal force, but it seems more than likely that Newton arrived quite independently at his conclusions concerning the problem of circular motion and was able to express the pull away from the center as a quantity proportional to the square of the velocity and inversely proportional to the radius of the revolution, the force varying as the radius and inversely as the square of the time necessary to complete the revolution.

Now applying Kepler's harmonic law, which was based on Tycho Brahe's observations, the periods of the planets should be proportional to the cubes of the radii. The simplest algebraic transformation showed then that the force holding to the sun any planet which obeyed Kepler's laws must vary inversely as the square of the distance. Could the nature of this

force be anything with which he was familiar, was the question in Newton's mind.

Tradition tells us that while Newton lay relaxed one day in an orchard beside the Witham, musing over this problem, a ripened apple fell from the branch overhead. Just where it struck or whether it hit Newton at all we have no authentic record. One thing is certain: from some such simple phenomena of nature Newton's consciousness awoke to the possible extension of gravity skyward to the moon. There high above the trees rode the satellite of the earth, pursuing a nearly circular orbit about our planet as does our planet about the sun. Could it be, thought Newton, that this very same force which brings the apple to the ground extends yonder and is pulling the moon continually from a straight-line course causing it to describe its curvilinear orbit?

If such was the case it could easily be checked by his inverse-square hypothesis, provided he knew the exact distance to the moon. The distance of the moon from the earth was known to be sixty times the earth's radius. Therefore, reasoned Newton, if gravity is the force responsible for the moon's curvilinear path and varies inversely with the square of the distance from the earth's center, then the actual force of gravity at the moon should be only one thirty-six hundredth of the pull on a body near the earth's surface.

The pull of gravity at the earth's surface had been carefully measured by Galileo and others in terms of the speed of falling bodies. It was generally known in Newton's day that a body released under the influence

of gravity would fall 16 feet in the first second and would attain a speed of 32 feet per second at the end of the first second. This amount of velocity would be added to a falling body's speed each successive second. It is called the acceleration due to gravity. If Newton could show that the moon fell from a straight-line course one thirty-six hundredth of this amount he would prove his theory. To get his results in absolute units he must know the size of the earth. It was common knowledge among navigators that there were 60 miles to a degree along the earth's equator, which led Newton to infer that the radius of the earth was 3,436 miles.

Calculation on this basis showed the moon to be falling to the earth about forty-seven thousandths of an inch a second. Multiplying by the factor 3,600 he should have obtained the rate of fall at the earth's surface, or 16 feet a second. But instead he obtained only 14 feet per second. Doubtless if this had been in modern times the discoverer would have minimized the discrepancy and announced his theory as substantially proved. Not so with Newton. He felt that this error was far too large to justify any such conclusion. Somewhat discouraged, he abandoned all thought of his gravitational problem for a time and diverted his attention to playing with light beams, inventing the reflecting telescope and writing on optics.

Years later (1672) Picard of France reported to the Royal Society on the results of a careful measurement of the earth's surface along the meridian near Paris. The length of one degree was nearer 70 miles than it

was 60. Word at length reached Newton, who was now Lucasian Professor of mathematics at the University of Cambridge. Realizing the importance of Picard's work in determining the size of the earth, Newton once more thought of his gravitational problem. As he pondered about the effect of the new value of the earth's radius upon his earlier result he realized that this new value might make all the difference in the world in checking his theory of the moon's motion. He began again to calculate the size of the moon's orbit and the amount by which, with this new datum, the moon fell toward the earth in 1 second. It was now fifty-three thousandths instead of the forty-seven thousandths he had previously calculated. Would this quantity multiplied by the 3,600 factor give the known fall of bodies at the earth's surface? If so, it should give 16 feet the first second. Perhaps even now, after all these years, he had been right and gravitation was the secret force controlling the operations of the universe! His biographers tell us that as he made the final calculation his emotion overcame him and he could not move his hand when he foresaw the result. Dropping his pencil, he cried out to his attendant, "Work it out for me. I cannot complete it!" His assistant completed the calculation. "What do you get?" "Sixteen feet per second!" was the answer. His law was verified.

The law of inverse squares had stood the supreme test. It had been checked by experiment. The force that holds the moon in her orbit was found to be the same force as that which pulls the apple to the ground.

The same mysterious force guides all the planets in their orbits. It was only a matter of time before Newton had the mechanics of the heavenly bodies on such a sure foundation that it was possible to predict their motions with astonishing accuracy.

The inductive power of Newton's mind is nowhere better exemplified than in the generalization of his planetary problem into the law of universal gravitation, which is the foundation of all celestial mechanics. It states that every body in the universe attracts every other body with a force which varies as the product of the masses, and inversely as the square of the distance between the centers of the bodies. It was the grasp of the full significance of this proposition that explained a small outstanding discrepancy in Kepler's third law—a discrepancy which worried Kepler but for which he had no explanation. The square of the periodic time of Jupiter was notably a little different from the cube of its mean distance. As soon as the mass of Jupiter was taken into consideration the discrepancy vanished. In the case of the smaller planets the trouble had not arisen, for they were too small to give a mass which was significant when compared to that of the sun.

Another practical problem found its solution through Newton's law: the problem of the tides. Newton showed that the tides in the oceans on the earth's surface were due to the attraction of the moon. Thus, from the outset, the law of gravitation anticipated far-reaching consequences. It was the crowning achievement of nearly 2,000 years' search for a mecha-

nism of the solar system consistent with the facts of observation.

Contemporaneously with Newton lived Edmund Halley. Newton owed much to Halley. It was he who perhaps more than any one else "discovered" Isaac Newton. Newton seemed utterly oblivious to the publication of his researches. The actual work of seeing his celebrated "Principia" through the press as well as the responsibility of financing its publication was borne by Halley. It was Halley who, on the basis of Newton's theory, calculated the orbit of the great comet of 1682 and found it identical with that of the comet of 1607 and again with that of a conspicuous comet observed by Kepler in 1531. He rightly inferred that it was one and the same comet that had appeared on these several occasions and determined its period of revolution about the sun as 75 years. Furthermore, he ventured to predict that the comet would again be seen in the year 1759. Halley never lived to see its return. It arrived, however, as scheduled and was a further triumph for Newton's gravitational astronomy. Henceforth, the comet was to be known as Halley's comet, the last appearance of which was in 1910.

No small amount of concern was felt by the organized church which, utterly lacking in appreciation for the great scientific achievement, looked upon the prediction of a comet's return as interfering with the prerogatives of Deity. Were not comets sent as warnings of divine wrath to a sinful world! To explain this movement by "natural law" took from the sky the last remaining manifestation of the supernatural.

While scientists therefore gloried in the new triumphs as dispelling another superstition, the ecclesiastics vehemently denounced Newton as "substituting gravitation for Providence," as ushering God to the brink of his creation and politely bowing him out of the universe. Such is the reaction of those whose conception of a deity in creation is that of a worker of magic rather than the Spirit of order and purpose.

Unlike Galileo, however, Newton's greatness appears to have been appreciated by his colleagues. He was honored with the presidency of the Royal Society, given the political distinction of election to Parliament, and at length made Master of the Mint with a generous salary. On his death in 1727 his body was laid to rest in Westminster Abbey where lay the greatest of England's departed. So epoch-making was Newton's contribution to science that it seemed for a time as though the major problems of astronomy were all solved. This immediate reaction to his greatness is well reflected in the immortal lines of Pope:

> Nature and Nature's laws lay hid in night
> God said "Let Newton be" and all was light.

As is often true of great characters—and doubtless fortunately so—Newton was quite oblivious to his own greatness. His sense of proportion made his greatest achievements appear insignificant to him in comparison with the truth yet uncharted. In his closing years he spoke with customary reticence, "I know not what the world will think of my labors but to myself it seems that I have been but as a small child

playing on the seashore; now finding some pebble rather more polished, and now some shell rather more agreeably variegated than another while the immense ocean of truth extended itself unexplored before me."

The remarkableness of Newton's achievement is evinced by the fact that the laws of gravitation formulated in the "Principia" remained unmodified and unchallenged through almost 300 years of the most rapid scientific progress. It was not until 1915, when the *generalized theory of relativity* was propounded by Albert Einstein, that we find the development of a new system of celestial mechanics founded on postulates seriously at variance with Newtonian conceptions. Based on the proposition that all motion is relative and that the rate of change of motion is equally so, Einstein developed equations for planetary motion which bear a striking resemblance to those of Newton, but which contain additional terms necessitated by the more general premises. The additional terms do not become significant except for bodies moving at much higher speeds than those of the planets. So for all practical purposes astronomers continue to use the equations of planetary motion based on Newton's theory. It should be mentioned, however, that a small discrepancy in the motion of the orbit of Mercury which the theory of relativity has explained could not be accounted for on the basis of the older theory. But nothing could be further from the truth than the popular impression, sometimes broadcast, that Einstein has shown that Newton was "all wrong." Every view of science is but a partial picture of the whole.

None would have welcomed more the broadening of the conceptions underlying the theory of gravitation than Newton himself.

It will be appreciated that with the work of Newton, planetary astronomy was on a firm basis. The Copernican theory had been vindicated through the mathematical genius of Newton in applying gravitational laws to the mechanics of the solar system, and yet there was lacking that direct demonstration of the earth's movement about the sun which the Copernican theory demanded, the small yearly shift in a star's position which we call annual parallax.

Fortunately for astronomy, while Newton was perfecting its mathematical aspects at Cambridge, James Bradley (1692–1762) was interested in carrying on its observational side. Bradley was for a time professor of astronomy at Oxford and later the Astronomer Royal at the observatory in Greenwich. The ingenuity of another Danish astronomer, Roemer, in the invention and construction of astronomical instruments had brought about the greatest improvements in the precision of observations since the days of Tycho Brahe. With new methods of graduating circles Bradley was now determining the position of a star with such accuracy that it seemed almost impossible that he should not discover this long-sought-for angle of parallax. Patiently he accumulated page after page of observations. Minutely he compared his measurements of a star's position night after night. At length he discovered a suspected discrepancy. Surely enough a star did shift its position slightly during the course

of the year. Back it came to its original position at the end of the elapsed twelve months. To his complete amazement, however, each star showed exactly the same maximum displacement. Surely this could not be parallax. It was inconceivable that *all* the stars should be at the same distance from the earth. On the other hand, how could an astronomer ever hope to measure with any finality of precision the accurate position of a star if all stars went bobbing about with seasonal variation of twenty seconds of arc?

Bradley pondered long over this problem arriving at no solution of the mystery. One day while taking a boat ride he noted that the apparent direction of the wind-borne flag from the vessel's mast changed as soon as the vessel got under way. He rightly interpreted the apparent aberration in the direction of the flag as due not to a change in the direction of the wind—for the direction of the waves on the water did not change—but to the combination of the motion of the ship with that of the wind-borne flag. With this simple analogy before him he suddenly thought of the explanation of his star problem.

A star's direction was apparently displaced by the combination of the earth's motion about the sun with the motion of the light from the star. A generation before, Roemer had announced a discrepancy in his observations of the movements of Jupiter's satellites. This he had attributed to the fact that light travelled at a finite velocity and consumed some 16 minutes in crossing the earth's orbit, 186,000,000 miles in diameter. The aberrational displacement which Bradley

had discovered was exactly the amount demanded by combining the velocity of light with the velocity of the earth moving at 19 miles per second along its orbit. Thus, while disappointed in not finding the true angle of parallax of any star, he had discovered an apparent displacement equally patent in demonstrating the earth's orbital motion.

Bradley's aberrational displacement was twenty times bigger than any displacement due to parallax, as was afterward learned. It was a most important discovery, not only because it gave direct proof that the earth did move about the sun, but because it brought to light a small seasonal correction that must be made to every star's position before a search for more minute displacements could be undertaken. The problem of measuring the parallax or shift of position of the star, due to the changing viewpoint of the observer, as the earth was sometimes on one side of the sun and sometimes on the other, remained still unsolved. Each failure, however, only emphasized the extreme remoteness of the stars whose distance defied measurement even with improved instruments of great precision.

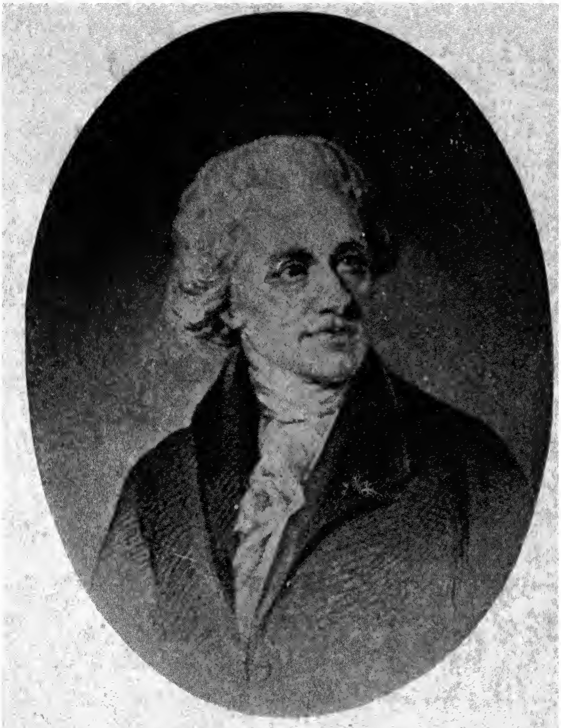

Plate IX.—Sir William Herschel.

CHAPTER VIII

Herschel. New Worlds and New Concepts

With the major problems of the solar system at last solved, astronomy could begin in earnest its attack upon the sidereal universe. One man whose name stands out preëminently as a pioneer in the study of the stars in space is William Herschel.

He was educated as a musician and appears to have been reasonably successful in music as a profession. Becoming interested in astronomy as a pastime he was ambitious to own a telescope. Telescopes came high. Herschel's wherewithals were low, so he determined to buy the materials and to make a telescope for himself. This he did. It was a huge success. He followed this with many others, increasing the size as he became more adept with the technique. Night after night he would spend in the open surveying the skies. Often he would slip out from the orchestra between the acts and take a look at the stars.

On one lucky night in 1781, curiously enough the thirteenth of March, he found an odd-looking object in the constellation Gemini. It was about equal in brightness to a star of the fifth magnitude but appeared distinctly larger than the surrounding luminous

points. He replaced the eyepiece in his telescope by a lens of higher power. The star was distinctly disk-like. Night after night he determined its position. It was wandering among the stars. Could it be a comet? Yet it had no tail nor any of the usual fuzziness of a cometary object. He communicated his discovery to the Royal Society. The orbit of the new strange object was calculated. It turned out to be a planet a hundred times bigger than the earth and revolving about the sun in an orbit far outside the planet Saturn. It was christened Uranus. Herschel was now on the road to fame. From the earliest days in astronomy through all the epochs of Ptolemy, Tycho Brahe, Galileo, and Newton astronomers had recognized Saturn as the outermost planet in the solar system. To be sure Galileo had added to the solar system by discovering the satellites of Jupiter, yet after all they were only satellites to a well-known planet. But here was another giant planet swinging around the sun at a distance twice as great as the distance of Saturn from the sun, obeying the same laws of gravitation which controlled the earth and moon, and brought the apple to the ground. But wait. Did it obey Newton's law of gravitation? Years passed. Its changing position was most scrupulously followed. It was wandering from its prescribed path. By the year 1840 it had wandered a minute and a half of arc from its predicted place. Such a discrepancy was unbearable to the astronomers. To be sure the amount, while grossly large when compared to the precision of astronomical observations, was only about equal to the thickness of a lead pencil

seen 50 feet away. The unaided eye could not possibly have detected the difference between the position of the actual planet and its predicted place. Yet it was sufficient to lead to astounding consequences.

Could it be that gravitation failed to follow strictly the inverse square law? Were the attractions of the neighboring planets, Jupiter and Saturn, sufficient to account for the difficulty? No, the perturbations due to these two planets were carefully calculated; they could not account for so large an error in the assigned place. Could it be that gravitation still held but that some other yet undiscovered body was attracting Uranus and interfering with its normal motion? Excitement over this problem was running high when a brilliant young student at Cambridge University became interested in the problem. His name was John Couch Adams. He graduated as senior wrangler and turned his mathematical ability toward the solution of the troubles with Uranus on the supposition of the attraction of an unknown planet. Long and hard he worked through the intricate computation and at length arrived at the position in the sky which the hypothetical planet was occupying.

With his results in hand Adams wrote a letter to the Astronomer Royal, Sir George Airy, telling him of his mathematical solution of the long-outstanding problem and the position in the sky where he believed the planet could be found with a sufficiently powerful telescope.

Airy opening his mail one morning came upon this strange communication. He looked immediately for

the signature. Reading J. C. Adams, a name utterly unknown to him, he pigeonholed the letter as probably of no value.

Meanwhile a brilliant young French mathematician by the name of Leverrier had become interested in the identical problem. Entirely unbeknown to Adams, he began working on the same hypothesis that the disturbances of Uranus were due to the action of another planet outside the orbit of Uranus, and proceeded to calculate its probable location in the sky. After one or two preliminary papers on the subject, which he promptly communicated to the French Academy, he arrived at the exact latitude and longitude of the hypothetical body. Like Adams he immediately proceeded to communicate his results to the Astronomer Royal. When Airy received the young Frenchman's letter stating just where in the sky the unknown planet might be found, he immediately sought to compare these results with those sent to him by young Adams. The earlier letter had been mislaid and only after some delay was it located again. To the great surprise of the Astronomer Royal, Adams' and Leverrier's results were in extraordinary agreement. Thereupon Airy thought it worthwhile to undertake a search for the new body. As there would be a certain national pride in being the first to sight the strange new member of the solar system, he would leave the work to no slipshod methods. It was decided, therefore, to organize a systematic search for the elusive body. He directed the making of accurate charts of the stars over a wide region in the neighborhood of the

suspected trouble-maker. He deemed it impossible that the position predicted by mathematical calculation could be very near the truth. Moreover to distinguish between a faint planet and a star would be difficult. A suspected object would have to be carefully watched many nights to make sure of its motion. This meant great labor in the intercomparison of star positions. Still he hoped a few months might suffice to reveal the lurking planet. Thus reasoned Sir George Airy.

Now, unlike Adams who was reticent and retiring, young Leverrier was aggressive and with his energetic qualities such as might characterize a high-pressure salesman, he left no stone unturned in his attempt to get the planet discovered without delay. Accordingly he wrote a letter to Dr. Galle, director of the observatory at Berlin. In a courteous but commanding style he told the German astronomer that if he would go into his observatory and direct his telescope to a point near the ecliptic at a given latitude and longitude he would see the new planet. Galle had excellent star charts. Taking Leverrier's letter at its face value he went out into the dome of his observatory as soon as it was dark, turned his telescope to the point in the sky that had been designated, and within a moon-breadth of the spot assigned found the faint pale green disc of the planet Neptune, making memorable in astronomical history the night of September 23, 1846.

Here indeed was the triumph of Newton's genius. The very laws of gravitation which for a time were thought at variance with the motion of Uranus had pointed with mathematical exactitude at an unexpected

spot in space and had said: "Look! and you will find a new planet." Man looked, and there it was just waiting to be discovered. Sir John Herschel speaking of it on one occasion said: "We see it as Columbus saw America from the shores of Spain. Its movements have been felt trembling along the far-reaching line of our analysis with a certainty hardly inferior to ocular demonstration."

I have broken the chronological sequence of Herschel's researches for the moment to follow to a conclusion the consequences of his discovery of the planet Uranus. This revealed what is perhaps the outstanding triumph of mathematical astronomy.

Hardly less significant, however, as a demonstration of the universality of Newton's gravitation law was Herschel's discovery of the nature of double stars. Realizing that the problem of determining a star's parallax was still unsolved, Herschel resolved upon an entirely new method of attack.

Bradley had endeavored to find a star's parallax by determining at different times in the year the exact position of the star in the sky with his finely graduated instruments. His labors had led to the discovery of the aberration of light, but so far as measuring the actual shift of position of a star due to its parallax, his results were nil. Herschel believed Bradley's failure in this was due to the fact that it was not possible to rely upon the adjustments of his instruments remaining constant over the necessary interval of time. Herschel reasoned that he would not attempt to determine the absolute position of a star for this purpose, but that

he would merely note the relative change of position of the brighter stars with respect to fainter ones close by. He reasoned that by and large the brighter stars must be nearer than the fainter ones. When, therefore, two stars appeared very close together in his telescope, one faint and the other bright, he measured the relative positions with great exactness, hoping that as the earth swung around the sun in its orbit he would see

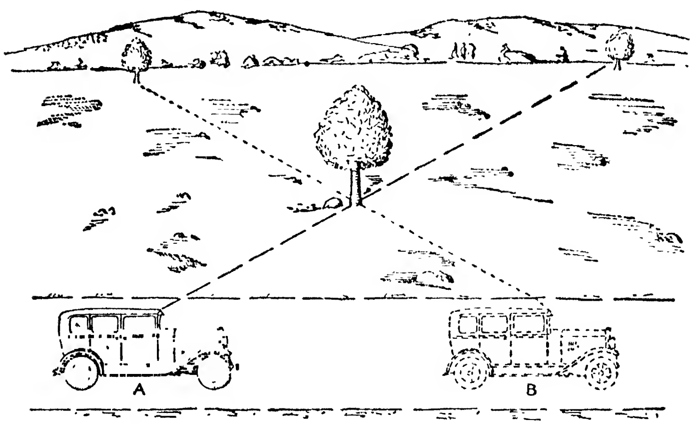

FIG. 14.—Displacement due to parallax. A tree appears to shift its place in the landscape as viewed from a passing vehicle.

the brighter star shift its position slightly with respect to the fainter and presumably more distant body.

This phenomenon of parallax is well illustrated in every-day travels by the shifting of nearer objects of the landscape with respect to those more remote. If we go driving along a highway, trees a hundred yards distant appear to drift by as we see them against the distant hills. Trees nearer move past more rapidly, while trees more remote may for a time seem to shift

their positions scarcely at all. We may drive for several minutes before we appreciate their slow drift against the distant horizon. The diagram illustrates that the nearer the object the greater does the shift of parallax become while the observer passes over a known distance, as from *A* to *B*.

If the distance over which the car passes is known and the angle of parallax is measured with suitable instruments, the distance to any object may be calculated. This is the method used by the surveyor in measuring distances across streams, to distant mountains, or other inaccessible objects.

Herschel found a great many pairs of stars which he selected for the purpose of determining parallax. These he watched most persistently, measuring with greatest care their relative positions night after night, month after month, year after year. Did he detect any motion? He certainly did. But to his complete amazement the brighter star was not moving around the fainter one as he had predicted. The fainter one was moving about the brighter. Moreover it was not a yearly motion. The movement was so slow that at least decades and in many cases centuries would elapse before a complete circuit was executed. Herschel had not discovered parallax, but something of even greater significance. He had discovered binary stars, systems of double suns revolving about a common center of gravity. Furthermore, the movements were in ellipses in accordance with an attractive force varying inversely as the square of the distance. Here at last was the great vindication of Newton's universal

law that had so boldly stated that every body in the universe attracted every other body with the same sort of force as that which pulled the apple to the ground.

With the idea of gravitational forces at work among the stars, the term "fixed stars" became a misnomer. No longer could the firmament be regarded as a static affair. Sidereal astronomy took on a new meaning.

The Rise of Sidereal Astronomy

Herschel's enthusiasm for observing the skies was unbounded. His excitement over discovering motion in binary systems fostered a resolve to let no corner of space escape his scrutiny. He built larger and larger telescopes. With each increase in size he could penetrate farther into space. His astronomical interests soon overpowered his musical ambitions. Receiving an appointment as telescope-maker to the King, he forsook his music for the stars and devoted himself thereafter to astronomy exclusively. His largest telescope was one measuring 40 feet in length and costing some £4,000 sterling. Herschel appears to have been of extraordinarily robust health and able to work with a minimum of sleep. He ground mirrors by day, and observed all night. His mind was continually on the stars.

Early in his observing career he systematically divided the sky into selected areas. He would survey every object within the range of his telescope at least three times and then pass on to the next adjacent region. In this way he covered the whole heavens several times during his lifetime.

A constant companion in both his daylight and his night labors was his sister Caroline. The polishing of his mirrors was a painstaking and tedious operation often requiring constant motion of the hand for hours at a time. To interrupt the process would change the temperature of the speculum metal of which the mirror was made, resulting in a distortion of its surface. Caroline would often feed him while he worked in order that there should be no interruption. She would often read to him for hours. He was particularly fond of the tales of the Arabian Nights. On clear evenings it was Caroline who was his favorite assistant at the telescope, faithful in recording positions of stars, or noting comments in regard to the appearance of various celestial objects as her brother might dictate. Perhaps it is safe to say that Herschel's output was more than doubled by her constant attendance upon his vigils.

Among the many discoveries of Sir William Herschel probably none mystified him more than the nebulae, those faint diffuse patches of light scattered here and there, of all sorts of shapes and sizes. With increasing power of his telescopes he would often find that these nebulae would break up into compact clusters of stars. Others, like the great nebula in Andromeda and the nebula in Orion, defied his strongest optical powers. Would these be resolved too into individual stars if only a powerful enough telescope could be built? This was a question constantly in Herschel's mind. He could find no answer. He liked to think of many of them as composed of primordial fire-mists, workshops of uncreated worlds.

In his survey of the skies he was greatly impressed with the enormous increase in the number of stars as his telescope approached the Milky Way. His scientific curiosity asked: "How rapidly do the stars increase in the neighborhood of the Milky Way?" He must know the answer. So he counted them. Selecting sample regions here and there at known positions with respect to the Galaxy, he undertook the counting of the stars within these fields. This, by the law of averages, would give him the requisite data for the answer to his question. He assumed the stars to be somewhat uniformly distributed in space and reasoned from his data that the universe must extend to greater distances in the direction of the Milky Way where the stars were most numerous. Near the poles of the Galaxy the stars were sparse. This meant that the direction at right angles to the plane of the Galaxy was the short dimension of a disk-shaped affair which contained the whole sidereal universe. He described the galactic system of stars as shaped somewhat like a grindstone. The sun, in his picture, was one of the stars somewhere near the center of this grindstone. As we on the earth were close to the sun we would look out and see stars in all directions. This made the starlit sky. The stars would appear most numerous when we looked out toward the rim of the grindstone. At right angles to this direction, along the axis of the grindstone, we would be looking through the universe in the direction of the thin dimension. Hence the fewer stars seen in this part of the sky.

When we consider how little our twentieth century picture of the galactic system differs from this picture of Herschel's, we can but marvel at the insight and brilliant imagination of this eighteenth century astronomer. Modern astronomy has added something to our ideas of the size of this affair, but as to its general shape we have not wandered far from the discoid characterization accorded it by William Herschel.

Perhaps an even bolder venture of Herschel's imagination is to be found in his belief that many of the faint disk-like nebulae were composed of millions of suns which in turn made up sidereal systems isolated and remote from our own galaxy. Island universes he dubbed them. Many of these, like the Andromeda nebula, twentieth century astronomy has verified as such "island universes," or other galaxies.

Well may we characterize Herschel as the pioneer in sidereal astronomy. Before his day astronomers had been occupied with the problems of the planetary system. The stars had been to them but fixed objects, too remote to be of interest except as reference points for marking the movements of the sun and planets or guiding ships upon the ocean. Galileo with his telescope had added greatly to the numbers of the stars, yet the starry void was to him still a mysterious veil and seemed to defy all attempts to discern its meaning. Now it was assuming shape, betraying a definite structure, dynamic in concept, with systems of revolving suns.

Patiently Herschel recorded night by night the precise positions of the stars, and day after day he

would compare his positions with those he had obtained earlier, and with positions in the catalogs of Flamsteed and of Bradley. Discrepancy after discrepancy arose. But he had learned well the lesson of science. He recognized discrepancy as the threshold of a new gateway to truth. If he could explain the discrepancies he would discover some new hidden phenomenon. He did. The errors were not due to observation. They must be real. The fixed stars were all moving among themselves, some this way, some that. It was not the motion of one star about another in a binary path. He was familiar with that. This was a drifting of a great swarm of stars. Nothing seemed to be fixed. As he compared and intercompared the observations he found that by and large in one part of the sky the stars all appeared to be moving out as from some radiating center. Directly opposite they were closing in. On either hand midway between these two perspective points they drifted slowly by. What was the meaning of it all? Was the sun and its system stationary in space while the universe of stars was drifting by? The old problem of relative motion again. If all the stars were moving, why not the sun also? Was not this common drift but the inevitable consequence of the sun's motion among them? Exactly. The stars were opening out ahead like the trees of a forest as one traverses the wooded road. Yes, and the stars too, like the trees, were closing in behind as the sun and earth receded from the vanishing point. Midway between these two apices in the sky the stars moved past like the trees close by on either hand. He made

a careful study of the point of perspective in the sky from which these stellar motions seemed to emerge, thus determining the point toward which the sun and its attendant planets were moving. This he located near the Milky Way in the vicinity of the constellations Hercules and Lyra. Similarly careful scrutiny of the motions of the stars in the opposite part of the sky revealed the vanishing point to be not far from the constellation of Orion.

Sit upon the observation platform of a transcontinental limited some night and watch the landscape. Dusky trees, lighted houses, signal lamps, lights of distant towns, and the dimly lighted rails all move rapidly by and slowly converge to a distant point far down the track behind the moving train. Just so we here on the planet earth occupy an observation platform-seat on the "Solar System Limited." Looking toward the sky we see the lights of distant stars. Slowly they converge toward Orion. So distant are the stars and so slow the movement that the naked eye cannot perceive them change at all in centuries or millennia, but the change is there, it can be measured in the telescope, and betrays the moving train on which we ride. Twelve miles a second, forty thousand miles an hour, four hundred million miles a year our sun rushes on through space from the region of Orion toward that of Hercules and Lyra. Will it continue so to move, or is it swinging on some great curve about a master center? Such was the question in Herschel's mind. This was a problem with which future astronomers would have to deal. It was enough

that Herschel should have sensed it and defined the sun's motion so clearly. Other stars too were moving and it soon became evident that the Great Dipper itself would, in the course of centuries, slowly change its shape, even to the naked eye, by the motions of the stars which composed it.

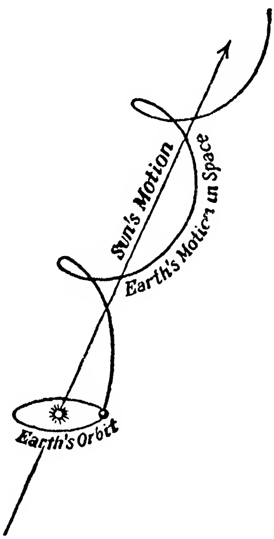

FIG. 15.—The sun's motion in space carries the earth along a gigantic helix.

How astronomy was changing man's conception of the skies! Hardly had the Copernican theory been settled. The idea of the sun as a stationary central body about which all the planets moved had but recently gained acceptance at large. Now Herschel set the sun in motion again. But it was not a return to a geocentric or Ptolemaic universe. It was the heliocentric conception of Copernicus with revolving planets,

but this time the whole system, sun and planets together, was being transported. The earth, while going about the sun, was also describing a gigantic helix in space. Whence we came no man knows. Whither we go, none can tell.

The conception is almost overpowering. Races of man, like midgets, throng the surface of a midget ball of dust. They are helpless, powerless to change their location or to stop or direct their moving earth. And yet here and there among this midget race there emerges some great consciousness, as of a Copernicus, a Newton, or a Herschel, which, rising like an eagle above the chattering sparrows, reads man's destiny among the stars.

CHAPTER IX

Cosmogony. The Beginnings of Evolution

WHILE Herschel had been busy with his telescopes creating a new stellar universe for men to think about, the mind of the philosopher had not been idle. Where did the world come from? This was the persistent question that had bothered the philosophers of all ages.

Primitive peoples had their traditions of Creation's story. The Semitic conception depicted in the first chapter of Genesis had satisfied Christendom and found the basis for an elaborate theology. An anthropomorphic Creator was depicted making something out of nothing by a single fiat, and then as a master craftsman, molding earth, sun, moon, stars, and man in six short days. Creation ended, the universe served as so much stage scenery for the drama of man. Some day, tired of his workmanship, and disgusted with his actors, this temperamental Deity would demolish his universe; the stars would fall from heaven, and the firmament be consumed with the fervent heat of the divine wrath. The theologians went so far as to fix the date of Creation at 4004 B.C. Appointed dates for the end of creation have been fixed many times by

various fanatical sects, and as many times have passed unnoticed.

In what contrast to this artificial setting was the universe revealed in Herschel's telescopes. Creation instead of being ended was still going on. Planets and stars appeared in all stages of development. Thousands of faint diffuse nebulae suggested systems yet unborn. All was in process of change. Was not Creation still progressing in one unending stream? Did not our earth represent a transient stage in one long, slow process of change? Were not the planets children of the sun? Were satellites born of planets? Or did sun, planets, and satellites emerge from some more primordial form of star-stuff? Such were the questions in the minds of those who thought of origins.

Among those who seem to have first devoted themselves seriously to ideas of cosmogony was Thomas Wright. He lived about the middle of the eighteenth century. It was through perusing some of the writings of this man that the immortal Immanuel Kant received much of his inspiration for philosophizing about the origin of worlds. It was Laplace, however, with whom we are concerned as the first to attempt anything like a detailed program for the development of the solar system from a primordial nebula, and thus to introduce into astronomy a scientific basis for the idea of evolution. Laplace's program appeared so feasible at the time of its promulgation, and so consistent with astronomical facts that it was destined to be the classical "nebular hypothesis" held by astronomers for nearly a century and a half.

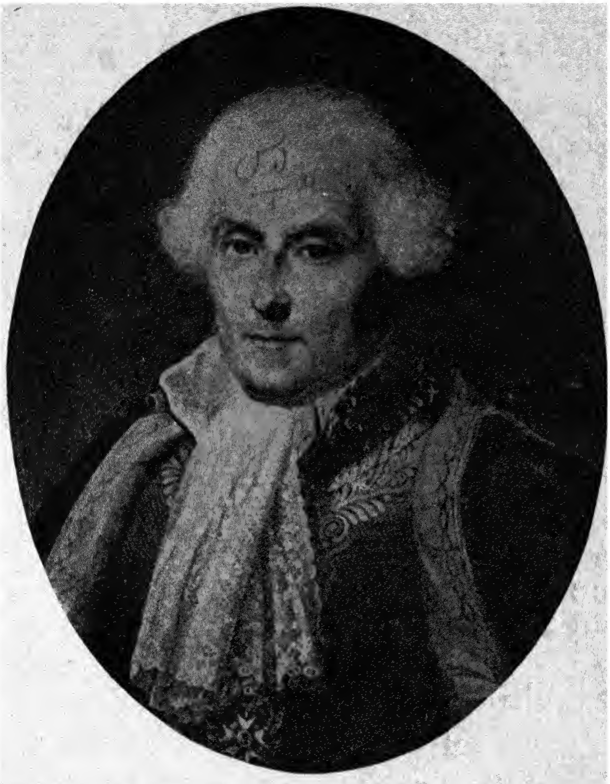

Plate XI.—Pierre Simon Laplace.

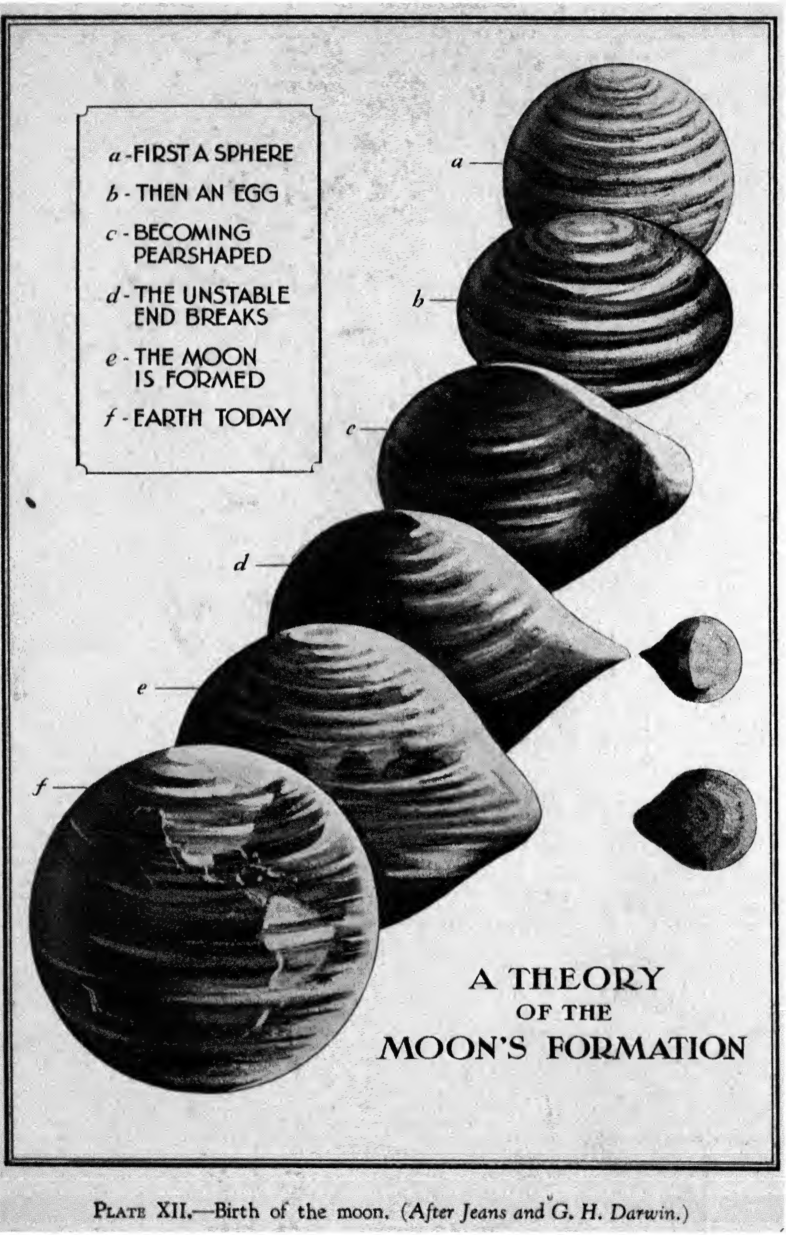

PLATE XII.—Birth of the moon. (*After Jeans and G. H. Darwin.*)

According to Laplace's theory, the whole solar system developed through eons of time from a widely diffused mass of gas or fire mist which extended far out beyond the orbit of the outermost planet. Through the Newtonian law of gravitation this highly attenuated nebula in Laplace's picture would gradually contract, presumably slowly rotating as it contracted. With the process of contraction came a quickening in its speed of rotation. Revolving faster and faster to conserve what in mechanics we call its moment of momentum, a stage would be reached when the centrifugal force would offset the gravitational force. Just as water would be thrown from the rim of a rapidly revolving wheel, so according to Laplace the outermost particles of the revolving nebula would be thrown off into space in all directions. This ejected matter would form a rim which would partake of a rotation in the same direction as the rotation of the major mass. Some of the particles thrown off in this outer ring would be larger than the others, and, therefore, form a center of attraction for surrounding particles. Soon, in this way, a lump of considerable size would result which would be revolving about the central mass, and at the same time spinning upon an axis of its own in the same general direction of rotation as that of the primary nebula. This whirling lump would gradually assume a spherical shape and become a planet in embryo.

Meanwhile the great primary nebula would go on contracting. The increase in speed would result in the detachment of a second ring, which in turn would

contract into a second spinning planet. Thus the process would go on. The main nebula contracting and increasing its speed would fling off more rings which in turn would form more planets. At last the innermost ring would be dropped and the planet Mercury formed. There now would remain of the original nebula but a dense nucleus. This nucleus would continue to contract, at length becoming a hot central body, or sun, rotating upon an axis from west to east in a direction common to that of all the planets.

While this major ring performance was going on, several side-show performances demanded attention. The many planetary masses that were formed from the detached rings, in turn, by their own rapid whirling and contraction gave birth to a second generation of rings which evolved into satellites. These satellites or moons circulate about the parent planets as do the planets about the sun. Thus, according to the picture, our own moon was born. So likewise came the moons of Jupiter and of Saturn. Indeed, what better argument could one find for the theory than the existing ring of Saturn still in evidence as a transient stage in this evolutionary process? I fancy it was the ring of Saturn which suggested to Laplace the ring element in the whole nebular hypothesis.

Collecting some of the facts in regard to the solar system, let us see just how consistent they are with Laplace's theory.

1. All the planets revolve about the sun in the same direction, counter-clockwise.

2. The outermost planet revolves the most slowly; the innermost the most rapidly, the speed increasing

with decreasing distance in accordance with Kepler's third law.

3. The planes of the orbits of all the major planets lie nearly in the same general plane as that of the earth's orbit, the ecliptic

4. The planets, with one possible exception, rotate on their axes in the same direction as they revolve about the sun, counter-clockwise.

5. The satellites of the planets, excepting the moon, are small in comparison with their primaries; and, so far as was known to Laplace, revolve about their respective planets in this same counter-clockwise direction as the planets themselves rotate and revolve.

6. The sun, a thousand times more massive than any planet, is still a hot, gaseous sphere, and rotates on its axis counter-clockwise with a period shorter than that of the innermost planet.

Thus far, all the above data appear to be entirely consistent with the Laplacian theory and to substantiate it. The nebular hypothesis was one of the greatest ventures of man's mind, and one can but marvel that such a flight of the imagination could be made in the eighteenth century and preserve so great a consistency with the observed facts.

But again the history of science repeats itself. Discoveries with the telescope continue, and the telescope is a heartless instrument. While it had revealed the satellites of Jupiter and Saturn, and the very ring of Saturn itself, which had presumably inspired the nebular hypothesis, it began to reveal disturbing circumstances.

Uranus had four satellites which were revolving about the planet the wrong way. Later, Mars was found to have two moons, the inner one of which was revolving about the planet faster than the planet rotated upon its axis. This was utterly impossible on the ring-origin hypothesis. Sadly enough, outer satellites of Jupiter have been found revolving about the planet in the retrograde direction. Many small minor planets have been discovered revolving in orbits badly tilted with respect to the planes of the orbits of the major planets, and what is worse, some of them revolve clockwise. But these were not all the troubles in store for the nebular hypothesis.

Mathematics is quite as heartless a tool as the telescope. Careful analysis of some of Laplace's assumptions prove that they were dynamically unsound. Material scattered widely in a ring will never by its own gravitation gather itself together into a planet. Furthermore, no mechanical process could be devised whereby 98 per cent of the angular momentum of the whole solar system could lie outside the sun itself. These were some of the facts that led to the discrediting of the nebular hypothesis in the latter part of the nineteenth century. It must not be inferred, however, that with the abandoning of the nebular hypothesis, as such, the idea of evolution of the solar system from some nebulous mass into an orderly system of planets and satellites was given up. It was the detailed ring-forming process of Laplace which had to be abandoned. Some new and more elastic theory would have to be devised.

Such is to be found in the planetesimal hypothesis of Chamberlin and Moulton, which marks the beginning of the newer cosmogony of the present century.

According to the planetesimal theory the close passing of two stars in space would, through mutual tidal action, cause an ejection of material which would distribute itself along spiral arms resembling the many spiral nebulae which we observe in great numbers in the heavens. As the ring of Saturn undoubtedly suggested the ring-mechanism to Laplace for his nebular hypothesis, so it appears that the photography of many spiral nebulae during the latter part of the nineteenth century suggested to Chamberlin and Moulton the idea of a new method of origin. In tracing the origin of the solar system in accordance with Chamberlin and Moulton's theory we must picture that in the dim distant past our sun and another star had a near encounter. Enormous tides of matter were drawn out from the surface of the sun and pulled into two huge spiral arms of nebulous gas by the passing star, which has long since gone its way. The general direction of rotation of this mass and the particles which it contained would be determined by the direction of motion of the passing star. Matter so thrown out would, to a large extent, fall back into the sun. But some particles having sufficient velocity would continue to circulate about the central nucleus. The intensely heated gaseous mass would rapidly cool, liquefy, and, to a large extent, solidify into material such as that from which the planets are made. By mutual gravitation larger lumps of matter would

gather in adjacent particles and we should have a planet growing by the accretion of the surrounding matter. Smaller particles of high enough initial velocities would have their motions controlled by the several nucleii and would become potential satellites of the planet. In this way the major planets in the solar system would grow from small condensed nucleii by the addition of immense amounts of meteoric matter. The minor planets circulating in various orbits between Mars and Jupiter may well represent some of the leftovers of the early planetesimals. On such a theory, satellites are never a part of the primary body and the moon could not have been part of the earth.

The planetesimal theory has the great advantage of being flexible. It allows for the retrograde motion of satellites and minor planets, for it would appear most likely that anomalous motions would grow out of the accidental encounters of the planetesimals. Some modifications of the planetesimal theory have been introduced through the investigations of Darwin, Jeffreys, and Jeans. The essential contribution of Sir George Darwin was the idea that tides formed between the earth and the moon while both bodies were in a semi-fluid state. These cosmologists favor the idea that the moon, for example, was once a part of the earth when it was in a plastic and mobile state. As it would appear unlikely that the rotating earth would be entirely homogeneous, a lump might very well form in the rotating planet which, by virtue of rapid rotation would soon lead to a condition of instability.

Jeans has shown that in such an instance a planet would change from a spheroidal to a pearshaped figure, at length resulting in the actual detachment of a portion of the planet. In this way the earth and moon may have resulted by fission of the parent body. Under these circumstances the moon would be revolving about the earth close to its surface with a rapid period of revolution. The enormous tides formed on both the earth and the moon, as has been shown by Sir George Darwin, would result in a force actually tending to separate the two bodies concerned. At the same time both the earth and the moon spinning on their axes would have to turn inside of enormous tidal bulges. These would produce distinct braking effects tending to check the speed of rotation of both the moon and the earth. At the same time the two bodies would be continually separating. Eons have passed while the moon has been attaining its present distance of 240,000 miles from the earth. Though once hot and plastic, in accordance with Darwin's and Jeans' theory, it is now a cold inert body. It appears likely that it solidified in an elongated, ellipsoidal shape with its long axis directed to the earth. Its period of rotation on its axis is now identical with its period of revolution about the earth, so that it always keeps its same face toward its parent body. This could have been no accident. It would be the natural outcome of the tidal theory. Looking into the future we can picture still further some of the consequences of such an evolutionary theory, for evolution is one unending stream of change. The tides formed in the oceans of the

earth by both the sun and the moon are continually tending to slow down the earth's period of rotation on its axis, in other words, to lengthen the day. While there may be at present some counteracting effects, in the long run it will appear that this tidal friction must produce serious results. Looking ahead into the dim, distant future, according to such speculation, we see a time when the earth's rotation will have been so retarded that the day is as long as the year. A tidal wave caused on the earth by the sun will then have a retarding influence on the speed of the moon in its orbit. By virtue of the reduced velocity the moon will fall into a smaller orbit. The process will continue with only one ultimate conclusion—the moon will fall to the earth. This will probably result in the complete wreckage of the latter, so far as man's pastimes are concerned.

We have now traced briefly the idea of evolution in astronomy so far as the formation of the solar system is concerned. While no theory is completely satisfactory in its details, it represents a great venture of imagination in trying to describe some of the possible stages through which such systems pass. So far as the evolution of stars themselves is concerned, and what may be their life history, we shall defer the discussion to another chapter.

III

The Changing Universe

The records grow.
Unceasingly, and each new grain of truth
Is packed, like radium, with whole worlds of light.

—Alfred Noyes.

CHAPTER X

The Birth of Astrophysics

IN THE year 1859, the same year in which Darwin published his "Origin of Species," there was introduced into astronomy a new method of analysis. It was due to the invention of the spectroscope, which was to make possible the study of the chemical composition and the physical properties of the stars. As the "Origin of Species" introduced into biology the possibilities of organic evolution, so the spectroscope introduced into astronomy the possibilities of classifying and arranging stars in a sequence of progressive inorganic evolution.

It was Sir Isaac Newton who tried the now celebrated experiment of allowing a beam of sunlight to fall upon a prism of glass. A beautiful band of rainbow colors resulted, which we call the spectrum. Newton decided that white light was composed of all of these several colors. He could reunite them by a lens and produce again the original white light. Newton failed, however, to discover the primary phenomena of spectrum analysis because he did not use a sufficiently restricted light source to perceive certain small gaps in this array of color produced by the sunshine.

Wollaston, in 1802, used a very narrow slit, through which was admitted a beam of sunlight. He passed this beam of light through a prism, obtained the familiar spectrum of rainbow colors, and noted curious faint dark lines crossing at right angles to the general direction along which the spectrum spread. Wollaston did not know the significance of these lines.

In 1814, Fraunhofer, a brilliant German optician, made an extensive map of these dark lines, designating the more conspicuous ones by letters of the alphabet. These letters are still frequently used by modern astronomers in referring to what have come to be known as the Fraunhofer lines. But Fraunhofer, like Wollaston, could not interpret their significance. The theory of radiation had to be more thoroughly developed before the true meaning of these lines could be understood.

Newton had conjectured that whenever a candle was lighted minute particles, or corpuscles, were shot out from the hot flame. These, when received by the eye, produced the sensation of light. He explained the reflection of light from a mirror as one explains the rebound of a billiard ball from a cushion. He explained also the refraction or bending rays of light by a glass prism or lens. There was one thing, however, that could not be explained on the basis of Newton's so-called corpuscular theory. This was the apparent bending rays of light into shadows. For example, I hold a sharp knife in the path of a beam of light so that it casts a shadow on a cardboard screen. Careful scrutiny shows that the edge of the shadow is by no means as sharp

as the knife edge. Some of the light, which was presumed to travel in straight lines, must actually bend a bit after passing the straight edge so as to give a feeble illumination along the edge of the shadow. This is known as the diffraction of light.

It is to Huyghens that we owe an entirely different conception of light, which will explain this phenomenon of diffraction. He conceived all space as filled with a hypothetical substance called the luminiferous ether. A luminous body agitates the ether as falling pebbles agitate the surface of a pond. Waves radiate in all directions. When these waves or undulations reach the eye it receives the sensation of light. Huyghens explained the reflection and refraction of light which Newton had explained, but went further and explained why shadows were not sharp, and how light actually bent around corners. Every one who has watched the entrance of an ocean wave through a breakwater knows that the wave spreads after passing the edge of the breakwater. No promontory can completely check this phenomenon. So Huyghens reasoned that light-waves spread, on passing a straight edge, and produced the phenomena of diffraction.

Until the beginning of the present century this undulatory or wave theory of light remained practically unchallenged. While now it fails utterly to account for certain observed phenomena in subatomic physics, it is still useful in explaining the majority of optical phenomena.

On the basis of the wave theory of light, the atoms of each particular chemical element, when duly

excited, give out a certain definite set of waves which are not duplicated by the atoms of any other element. When these waves of light are passed through a prism they will be bent a certain definite amount, according to their wave length. The wave length is the actual distance between successive crests in a train of waves from a given source. The length of a wave of light is about one fifty-thousandth of an inch; some waves are longer, some are shorter. Waves produce on the eye different color effects, depending upon their wave length. The longest waves which the eye can perceive give us the sensation of red, the shortest the sensation of blue light.

If I burn a bit of ordinary table salt in a hot gas flame I get an intensely yellow light. This light is due to the element sodium, one of the principal constituents of common salt. The atoms in the sodium are agitated by the intense heat of the flame and send out waves of a very definite wave length, giving us the sensation of yellow. The wave length of this sodium light is 0.0000589 centimeters. When this wave strikes a prism it will be bent at a very particular angle and will come through as a narrow beam of yellow light of the original color. As it is of one definite wave length or, as we might say, homogeneous, it cannot spread out into several colors.

If in addition to the ordinary salt (sodium chloride), which I scattered into the gas flame, I introduce a salt of strontium (strontium chloride) I get now a very brilliant orange-colored flame. If we pass this orange light through a prism we find that it does not come

through as orange light, but that it is separated into two distinct beams, the old familiar yellow beam due to the sodium, and a new and intensely red beam due to the strontium. If I look into the prism I see two distinctly separated gas flames, one yellow, the other red. Each of the two beams is refracted at its characteristic angle, which depends upon the wave length of the light, the red image being due to the light of a longer wave length than that producing the yellow image.

If I were burning hydrogen gas I should see three distinct images when looking through the prism, as hydrogen sends out principally three distinct trains of waves. The positions of the beams of light coming from the prism will tell us exactly the wave lengths of the light. If I were to have a source of light giving all conceivable waves I should then get a continuous spectrum formed with all the colors stretching from red through orange, green, blue, and violet. Such is the case with the use of light from a hot solid body such as the filament of an incandescent lamp.

If now I should put between the source of white light and my prism spectroscope a large mass of cool sodium vapor, this sodium vapor would absorb from all of the various wave lengths of light coming from the source that very particular wave length (0.0000589 centimeters) which the sodium vapor would emit if of itself luminous. As the wave length of sodium light represents a very narrow region of the spectrum, we must be particular to see that the size of the source of light is restricted to narrow dimensions in order that the overlapping images shall not confuse our observa-

tion. Accordingly, in a professional spectroscope a very narrow slit is used next to the light source, and it is the images of this slit which make up the spectrum of the source. With the slit introduced an observer will have no difficulty in seeing that there is a distinct gap in the yellow of the continuous spectrum in the experimental set-up just described. This is due to the fact that the sodium vapor, at a lower temperature than the light source, has absorbed from the original source that specific band of color which would have been contributed by the sodium vapor itself, if luminous. This little gap in the spectrum therefore has all the appearance of a dark line. It may be identified as due to the intervening sodium vapor for it occupies exactly that position in the spectrum which is controlled by the emission of light from burning sodium. In the case of the sun we find that the spectrum of its light is crossed by innumerable dark lines. Almost all of these have now been identified as occupying the positions of bright lines which can be produced by the burning of well-known elements in the laboratory. This interpretation of the dark lines of the solar spectrum was due primarily to Kirchoff, in 1859, and marks that year as the true beginning of the study of the physical nature of stars, or what is commonly termed astrophysics.

Immediately after the full significance of the spectroscope was appreciated as a new adjunct to astronomical research, it was attached to the telescope and made possible for the first time the analysis of the light of distant stars. And what a revelation it gave! It told

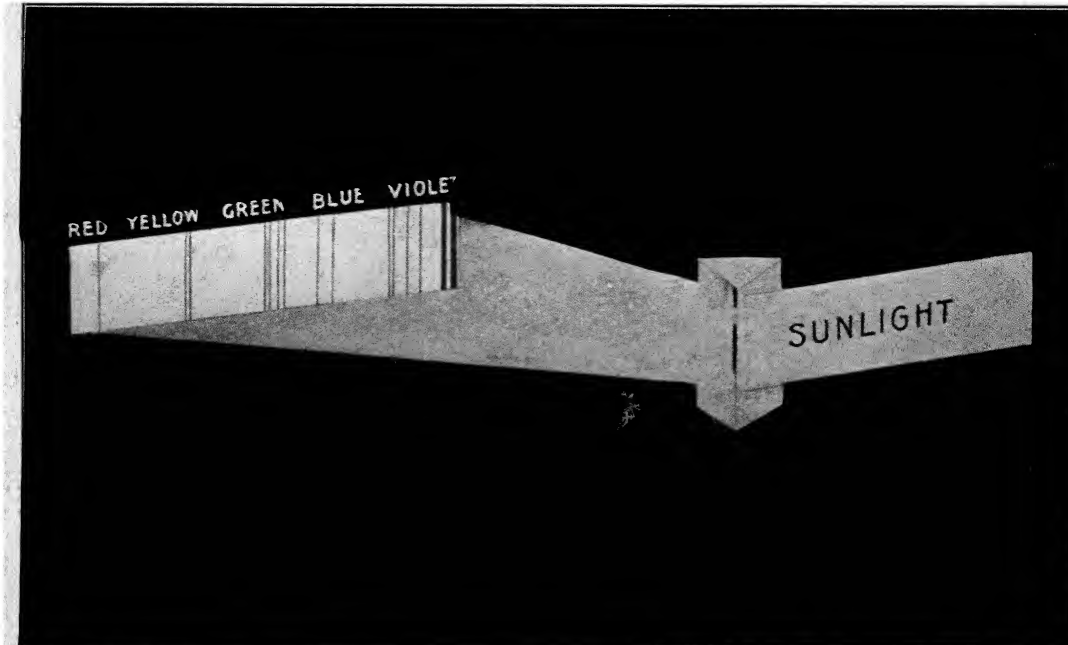

Plate XIII.—The formation of a spectrum. When a beam of sunlight is admitted to a darkened room and is passed through a prism of glass, a spectrum is formed consisting of all the colors of the rainbow.

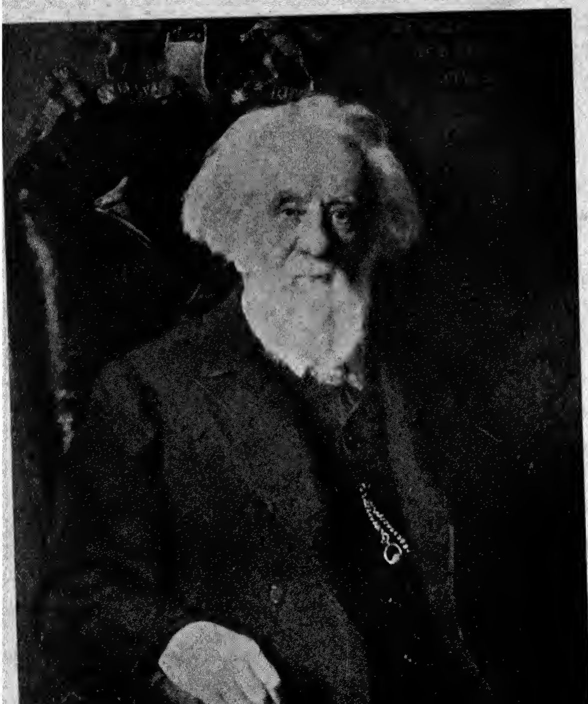

Plate XIV.—Sir William Huggins.

that all the stars were suns like our sun, many of them identical in their composition, showing a spectrum almost the exact duplicate of that of the sun itself. Almost all the stars showed continuous spectra crossed by dark lines; in many cases the prominent dark lines were due to hydrogen, in other cases to helium. Other stars, usually deep red in color, showed lines broadening into dark bands similar to those produced by the oxides of elements in the chemical laboratory. The heavens took on a new significance. The stars were crucibles in which atoms of all sorts were agitated at temperatures unknown on earth. Little by little close resemblances were noted among the spectra of the various stars; it became possible to classify them, and to arrange the stars in a sequence, as the zoologist arranges the specimens in his museum. The old question of Herschel's "of what are the nebulae composed?" was again revived. Could nebulae be split up into clusters of innumerable stars if we had powerful enough telescopes? These were the questions left unanswered by William Herschel. Could the spectroscope help out in this dilemma?

It was Sir William Huggins, a pioneer in astronomical spectroscopy, who sought the answer and first gave it to the world. One night in 1867 he turned his telescope with spectroscope attached toward a small nebula in the constellation Draco. He looked through the instrument. There was no continuous spectrum. He saw only two or three bright lines. What could be wrong with his instrument? He carefully went over the adjustments. Yes, the starlight was surely falling

on the slit. Again he looked into the spectroscope. The glowing of a faint green line caught his eye. A few other faint luminous lines accompanied it. This was the spectrum of a glowing gas, not of a cluster of stars. The mystery of the nebulae was solved.

Excitedly he turned his telescope toward the great nebula of Orion, that curious ill-formed cloud of light surrounding a star in the sword of this hero of the sky. Again the spectroscope showed bright lines. He turned it to a star. A continuous spectrum crossed by dark lines put in its customary appearance. Back again to the nebula he went. The faint green line betrayed the secret. When he looked more intently, faint but luminous lines of hydrogen appeared. The Orion nebula was not an aggregation of stars. It was in very truth a glowing gas. It gave forth the characteristic isolated lines of hydrogen excited by the discharge of electricity. This could be duplicated in any laboratory. The faint green line could not be matched against the light of any known element. Could it be due to some new substance not known on earth? Until very recently such has been believed to be the case. This hypothetical substance which glowed in these distant cosmic clouds was accordingly named nebulium.

It was not until the year 1927 that the mystery of nebulium was solved, when Bowen, working in the laboratories of the California Institute of Technology, found that the characteristic green line of nebulium was due to the light emitted from oxygen and nitrogen in a peculiarly excited state of electrification. Not all nebulae, however, are in the gaseous state of those

just mentioned. The great Andromeda nebula shows a continuous spectrum crossed by dark lines characteristic of the sun and stars, and we know now that it is an aggregation of stars so thickly packed together that no telescope short of the super-giant instrument at Mt. Wilson in southern California can resolve it. So we see that Herschel was partly right and partly wrong in his conception that nebulae might be aggregations of stars on the one hand or vast stretches of cosmic gas on the other. Evidently the nebulae are of at least two very distinct classes.

With the ability of the spectroscope to discover in such nebulae more primitive forms of matter than was found in the stars themselves, it became the ambition of astronomers to try to arrange in an evolutionary sequence all cosmic objects in such a way that their spectra might proceed by definite steps from the bright-line type of the gaseous nebulae to the banded spectra of the dullest red star. This problem outlined, rapid progress was made by Father Secchi in Europe, and Pickering and his co-workers at the Harvard Observatory in this country.

By the beginning of the twentieth century the accepted doctrine of stellar evolution was that in some strange way stars would evolve from hot nebulous masses at exceedingly high temperature—perhaps 40,000° F. Bright stars in the constellation of Orion, giving the bluest light, were therefore thought to lie near the top of this scale, and represent some of the stars in the earliest stage of stellar development. Other stars with characteristic stellar spectra exhibited

the peculiar characteristics of certain bright lines in addition to the characteristic dark absorption lines crossing their spectra. These were thought at the time to be a connecting link between the strictly bright line, gaseous nebulae, and the earliest stages of the hotter stars. Letters of the alphabet were used in

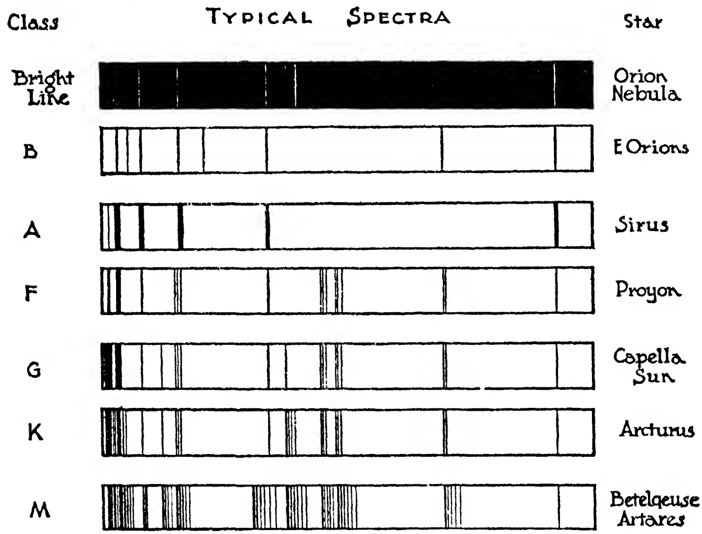

FIG. 16.—Fundamental differences in typical stellar spectra.

order of their sequence to represent the divisional classification of the stars observed at Harvard and after a considerable rearrangement the following order came to be generally accepted as the most likely one for a program of stellar changes:

O, B, A, F, G, K, M,

While all this observational work was in progress, theoretical workers had not been idle in attempting

to add their contributions to the evolution of sun and stars. One of the most important advances in understanding the physical development of stars came about through the researches of Helmholtz about the middle of the nineteenth century. Helmholtz, searching for a possible source for the maintenance of the sun's heat, came to the conclusion that an enormous source of energy could be supplied through the contraction of a gaseous body under its own gravitation. Lane, of Washington, announced the curious paradox that a gaseous body contracting under its own gravitation would rise in temperature until by virtue of increasing density it ceased to be a perfect gas. At this stage it would radiate about as much heat as would be generated by its retarding contraction and for a period would remain at constant temperature. With a continuation of contraction, however, the density would become so high that the body would no longer generate heat as rapidly as it lost it, and a decline in the temperature of the body as a whole was therefore inevitable. Helmholtz applied this law of Lane in an attempt to tabulate the amount of shrinking necessary for the sun to perform in order that it should maintain the present rate of radiation. This he found to be not over 300 feet a year in the solar diameter. Reasoning into the past, he calculated that the sun could not have been maintaining its present rate of radiation for more than 20,000,000 years. Meanwhile, geologists were contending that studies in the structure of the earth's crust, the degree of salinity in the ocean, and other cogent data pointed to an age for the earth of at least

100,000,000 years. No solution of the dilemma thus created appeared probable until some new discovery could throw light upon the problem. The discovery of radium by the Curies and the birth of the new science of subatomic physics have unlocked new sources of energy that make it appear possible that the age of the sun can be extended a hundred to a thousand times the duration assigned it by Helmholtz. Furthermore, the study of radioactive deposits in the earth's crust gives new evidence that the age of the earth is many times the hundred million years earlier set by the geologists.

Irrespective of the bearing of the Helmholtz contraction theory on the age of either the sun or the earth, it introduced a new element into the idea of stellar evolution. It was no longer necessary to suppose that stars must evolve from superheated gases and start their career at the high temperature end of the scale. Indeed a cold gaseous mass, by virtue of its contraction and gravitational forces, would gradually rise in temperature, attain a critical maximum on the temperature scale, and then cool down indefinitely until it became a nonluminous body. If such were the case, stars would first become luminous as dull red bodies highly diffused and of enormous dimensions; gradually shrinking, the redness would change to yellow with the increasing temperature. Further contraction would result in the generation of greater heat until the star became literally white hot. The spectrum at such a stage might very well be that of some of the Orion stars corresponding to the letters *B* or A in the accepted

list. Continued contraction would result in increasing density and, presumably, a general decrease in temperature. As the star cooled, its color would pass from white to yellow, again to red, and perchance ultimately become too faint for visibility. In these latter stages its dimensions would be many times less than that of the earlier stages in the sequence. Lockyer, Hertzsprung, and in this country Russell, have been preeminent in working out the details of such a program of the stars' development.

Red stars in the earlier stages of this evolutionary sequence were called giants, those in the latter stages dwarfs; and the whole theory has been termed the giant and dwarf theory of stellar evolution. The bright red star Antares in the constellation of Scorpius, and a similar red star, Betelgeuse, in the constellation of Orion are typical giant stars, and are easily a million times the size of our own sun, which is probably quite typically a dwarf. It will be seen that this idea of a double sequence from low to high temperature and back again entails a considerable amount of unscrambling of the classification of stellar spectra previously outlined. Twentieth century astronomers are busy discovering minute differences in the appearances of the lines of spectra of the different classes, which will distinguish the giants from the dwarfs among stars of the same color. Astronomy and physics have gone hand in hand for the solution of this problem.

Just what becomes of a star after it reaches the red dwarf stage is problematical. A decade or so ago astronomers would have probably said that it became

a cold dark star with no hope of rejuvenation, unless perchance in its ramblings through space it collided with another star or with some dark cloud of interstellar matter. In such an event the energy released upon impact would be sufficient to raise the temperature of the star so that it would again become incandescent. In fact, the occasional outburst of a nova or new star in a previously unmarked region was usually attributed to such a catastrophe.

Our views in regard to the ultimate fate of a dwarf star have been rather seriously modified of late through the discovery of two or three extraordinary specimens of the dwarf type. The most outstanding individual of this nonconformist group is a very peculiar little fellow which hovers about the bright star Sirius. Now this companion to Sirius is altogether a faint star, giving out only about one three-hundred-sixtieth of the amount of light emitted by our sun. On the other hand, the spectrum is that of a white-hot star like Sirius itself. We know very well the distance to this system, and can therefore deduce the area of a radiant surface of this temperature which would just produce this amount of light, that is one three-hundred-sixtieth of that of the sun. The diameter of the body comes out to be only about one-nineteenth that of the sun. Surely this is a dwarf star if there ever was one. The abnormality is that it is not red. But this is not the only trouble. The swaying of Sirius in an orbital motion under the gravitational pull of its companion tells us that the mass of this little fellow is nearly the same as that of our sun. Now for a star to have only

one-nineteenth the diameter of the sun and yet to contain almost as much matter means that it must be made of ridiculously heavy stuff 2,000 times denser than platinum, the heaviest known terrestrial element. If this book were made of such material, it would have to be issued in eight or ten volumes in order to be transportable. Even so, each volume would require a 5-ton truck for delivery to your door. You would surely need some mechanical assistance beside you as you read it, for it would require a 300- or 400-pound lift every time you turned a page. Enough of such nonsense, you say. Such material is too absurd to imagine! That is just what the astronomers thought a few years ago. But be patient a moment; truth is often stranger than fiction.

In 1924, Professor Eddington, working on theoretical grounds, came to the conclusion that the excessively high temperatures in the interior of stars would so smash up the atoms that they could be jammed together into just such a mass of unimaginable density. Fortunately there was one experimental way in which his theory could be verified. According to Einstein's newly proposed theory, light waves coming from so dense a star should be considerably lengthened. This should be made evident in the spectroscope by a predictable shift of the lines in the spectrum toward the red. The same year in which Eddington announced his conclusions Dr. Adams of the Mt. Wilson Observatory discovered this very shift in the spectrum of the companion of Sirius. Thus, at last, came the experimental verification of the existence of this fantastically heavy star stuff.

In the breaking down of the very atoms themselves under such conditions of temperature and pressure as must exist in a dwarf star of this type it seems reasonable to suppose that the enormous amount of energy suddenly released may well percolate through to the exterior of the star so that what may have been previously a red star becomes a white-hot star again. Thus we may account for the white dwarf star, and at the same time provide ourselves with a new theory for a star's rejuvenation. Jeans would have us believe that our sun right now may be in a perilously unstable state already to "blow up" any minute through the advent of some such catastrophe. While the stars have told us much about the nature of matter by revealing it to us in unfamiliar states, a further understanding of the structure of the atom will go a long way toward helping us predict the future of the stars.

CHAPTER XI

Atoms and Stars

WE HAVE as yet no completely satisfactory theory of radiation of light. Modern physics has done much, however, toward giving us some sort of picture of the structure of matter which has made possible the explanation of many of the simpler problems in spectroscopy.

Back in the days when the atomic theory of matter was taught in every chemistry class as the ultimate, a student was asked to distinguish between the atom and the molecule. In that somewhat hesitant and diffident manner that is often characteristic of no superabundance of knowledge he said, "Well, Professor, I think the atom is about the usual size and the molecule is the size next larger." If such an anecdote will serve to illustrate the conception of matter a generation ago, we shall have to revise it today to say that if the atom is the usual size the electron is the size next smaller. It is perhaps at first a bit surprising that astronomers who have to deal with inconceivably great distances should at the same time be intimately concerned with the smallest dimensions known to science, the sizes of electrons and atoms. No one knows what an electron is, but the word has served a very

useful purpose in giving us some sort of building block out of which could be constructed all sorts of things: atoms of gases, molecules of compounds, stars, rocks, and even human beings. It would be, perhaps, quite futile to attempt the latest picture of the ultimate nature of matter, for physical science is changing so rapidly that what today is, tomorrow may be cast into the oven. However, we have one picture of the simplest known atom, that of hydrogen, which through the genius of Rutherford, Bohr, and others has served admirably for the more elementary consideration of the nature of radiation.

We may picture a hydrogen atom as a miniature solar system, the central nucleus of which controls the motion of a circulating electron much as the sun controls the motion of a planet in its orbit. The distance between the electron and the nucleus probably compares with the size of the electron much as the distance to the sun (93,000,000 miles) compares with the size of the earth. It is suggested that if the dome of St. Peter's were to represent the size of the atom, a small fly buzzing around in its interior would well represent the equivalent of the electron. Our conception of the central nucleus is perhaps as definitely represented as the indefiniteness of a spot of space at the center of the dome. However, this indefinite center, supposed to be positively charged with electricity, contains practically the mass of the entire atom, about 2,000 times as great as that of the electron. To carry out our analogy, let us suppose that the habits of our fly lead him to circulate in an orbit about the central point.

So long as he is contented to fly in a circle of a definite radius the world outside of St. Peter's knows nothing of the existence either of the cathedral or of the fly within. Ever and anon, through some mysterious instinct, the fly suddenly exhibits the characteristics of another agile species of insecta which has the ability to hop from one place to another without leaving a trace of his transition in the interim.

The fly, therefore, which has been circulating in an outer orbit near the periphery of the dome suddenly appears to have jumped to an inner orbit, let us say of half the size, and merrily pursues his rounds as before in this circle of smaller radius. The world now knows of the existence of St. Peter's and also of the fly, for his action of passing from one orbit to the other has been announced by the emission of a radio wave from the cathedral to the remotest corners of space. It has travelled at the speed of light. This curious performance of the fly in passing from one orbit to the other has released suddenly a definite amount of energy and sent out a wave of light through the ether of a very particular wave length. If in another moment of capricious behavior the fly jumps to another orbit of still smaller radius the world again hears about the existence of St. Peter's and the fly within. Another bundle of energy has been released and another definite wave length broadcast. We have in this homely and altogether crude picture an analogy of what happens within the hydrogen atom when its electrons have been agitated, and light from luminous hydrogen gas is emitted. Each jump of the electron corresponds to a

particular line in the hydrogen spectrum, and the prism of the spectroscope will sort out the radiation so that the beam of light passing through the prism will come through at its characteristic angle corresponding to the particular wave length involved.

In general a given mass of hydrogen gas will contain many millions of atoms, each with its own electrons circulating about a nucleus and jumping from orbit to orbit without warning. We shall therefore get in the spectrum of luminous hydrogen a definite series of lines, the several lines of the series corresponding to the several specific wave lengths emitted by the electrons in jumping from orbit to orbit.

Let us suppose that our fly by some ecclesiastical decree must circulate about the center of the cathedral dome in orbits of only certain specified sizes. We have then an analogy of the restrictions on the motion of electrons which compel them to move in certain prescribed orbits within the atom. The series of lines in the hydrogen spectrum will represent all of the particular transitions which the electron is allowed to make so far as its choice of orbits is concerned. From the actual measurement of the wave length of the light emitted in these characteristic lines of hydrogen, the sizes of the several orbits which the electrons may pursue can be calculated.

The next simplest atom is the atom of helium. Here we will picture a central nucleus with nearly four times the mass of the hydrogen nucleus, containing four charges of positive electricity, and two electrons, which may be represented by two captured flies inca-

pable of flying about in orbits. Outside the nucleus, but within the dome of this helium atom, two flies are now circulating about the central mass, capable of jumping into certain specific orbits, similar to the case of the hydrogen atom. As the set-up of the atomic structure is quite different from that of hydrogen, we shall have broadcast to our spectroscope a series of lines very differently arranged from that in the hydrogen spectrum. Let us now introduce a new element into the situation. A sharpshooter approaching the cathedral from the outside fires a rifle bullet into the cathedral dome and hits one of the two flies buzzing about in the outer orbit. He has completely changed the characteristics of the atom within. Only one fly is left to pursue his solitary course, jumping from orbit to orbit in a way similar to our lone hydrogen fly. His choice of orbits, however, is quite different from those of the hydrogen fly, for the dimensions of these orbits are controlled by the constitution of a nucleus quite different from that of the helium atom. The wave lengths broadcast, however, by the jump of the lone fly will give a series of lines in the spectrum strikingly similar, though distinctly displaced from those of the hydrogen atom, and vastly different from that of the normal helium atom, which contains two circulating flies. In the vocabulary of the physicist, the sharpshooter has "ionized" the helium atom.

In 1896 there was discovered by Pickering of the Harvard Observatory a curious series of lines in the spectrum of a star photographed at the southern station of the observatory, then located at Arequipa,

Peru. The star was known as Zeta Puppis, belonging to a constellation visible only in southern skies. The arrangement of the lines in the spectrum suggested the familiar series due to hydrogen, but the position of the series did not at all correspond to the normal position of the lines in the hydrogen spectrum. Pickering, however, attributed them to hydrogen presumably in some state not familiar to chemists of the earth. The series has long since been known as the Pickering series. Many physicists sought to produce this peculiar series by exciting hydrogen gas in the laboratory in a variety of ways. At length Fowler in 1912 announced that he had been able to obtain this Pickering series by photographing the spectrum of hydrogen when the hydrogen was mixed with helium. Later investigations, however, showed him that the hydrogen was entirely unnecessary. The peculiar series of lines could be produced when helium gas was rendered luminous by a particularly vicious discharge of electricity. With the development of subatomic theories the explanation was soon forthcoming. The vicious electric discharge through the helium gas stripped off one of the two circulating electrons of the helium atom and left the atom ionized. The spectrum resulting, therefore, would indeed appear similar to hydrogen, for it was produced by an atom with but one circulating electron; on the other hand, it would be distinctly different from the normal hydrogen series because the nucleus was the nucleus of helium.

This incident illustrates very well how physics and astronomy have gone hand in hand in helping to solve

one of the most fascinating and important problems of modern science, the problem of the structure of matter.

Modern spectroscopists have now gone far toward explaining in a somewhat similar way the existence of thousands of lines in the spectra of various elements. Of course the atoms of the heavier elements are vastly more complicated in their structure than represented by the simple pictures of hydrogen and helium here given, yet it appears that the hydrogen atom is a pretty good sample of the building blocks out of which all substances are composed.

In attempting to build up more complicated atoms out of hydrogen we gain a possible clue to a storehouse of energy for the sun and stars not previously suspected. The helium atom, it will be recalled, is composed of four electrons and four positive charges, usually called protons. Two of the electrons are bound into the nucleus with the four protons. The other two electrons circulate about the nucleus. The atomic weight of hydrogen is 1.008. The atomic weight of helium one would expect to be 4.032. But this is not the case. The atomic weight of helium has been measured again and again with great refinement and is known to be 4.000. What has become of the extra mass represented by the decimal 0.032? Modern theory points to this discrepancy as a likely source of energy of radiation. It may very well be that the energy of the sun and stars is being continuously replenished by the forced combinations of the hydrogen atoms into the helium, under conditions of temperature and pressure unknown in any terrestrial labora-

tory. Such an atomic source of energy might well prolong the life of the contraction theory of Helmholtz already outlined.

But whatever the time scale may be we are presumably not far wrong in conceiving of the star's evolution as starting from an enormous ball of moderately cool gas. This ball of gas will inevitably contract and rise in temperature as its contraction proceeds, in accordance with Lane's law, which states that a gaseous body contracting under its own gravitation will gain in temperature so long as it remains perfect gas. It will pass through the red, yellow, and white-hot stages to its highest temperature and then cool down again through the yellow to a dull red stage as previously outlined on the basis of the contraction theory. It seems likely, however, that with our newer knowledge of subatomic energy the time consumed in this entire process is enormously extended.

Let us represent graphically the life curve of our sun, which is, after all, quite typical of any star. Along the width of the page is an attempt to represent a time scale, which extends into billions of years. Along the vertical dimension of the page I give the approximate temperatures which are presumably attained at the various stages of development. A little dot on the down-slope of the curve corresponding to a temperature of about 12,000° F. represents the present stage of our sun in the course of its life history. In order for us to appreciate something of the duration of the time entailed I should mark off a little section

of this curve for the length of the duration of the earth, but I am embarrassed at the attempt. As was stated earlier, our best guess at the age of the earth is probably two or three billions of years, and that stretch on the life curve of our sun is already completely covered by the little round dot. Probably the most optimistic anthropologist would not recognize his *homo sapiens* much further back than 50,000,000 years. Certainly no definite records of civilization antedate 6,000 years. But what are 6,000 years! We could not find a spot on

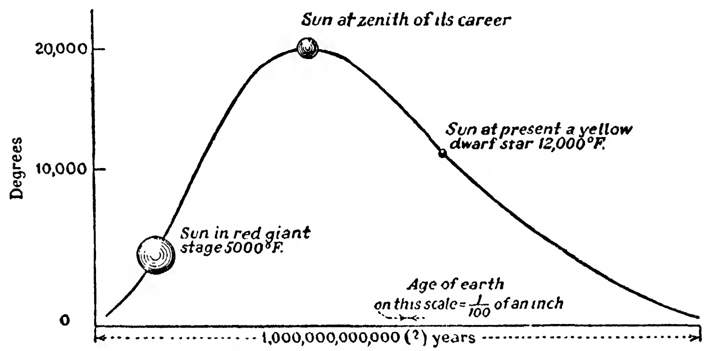

FIG. 17.—The life curve of the sun as a typical star.

the curve that could represent it. No, not if we had the most powerful microscope.

Since all that we have learned about astronomy has been done within comparatively few centuries, do not be too harsh in your judgments of the astronomer if he cannot tell you more specifically the detailed structure of this life curve of the sun, especially at its beginning and at its ending point. To revert again to St. Peter's at Rome, let us suppose that an ignorant man with no knowledge of history, art, or architecture,

were escorted into the interior of that cathedral at midnight with no lights of any sort. Imagine that he has not even been told that something is about to happen, and a flash cartridge of magnesium powder is suddenly set off. Our observer gets one momentary glimpse of the grandeur of the structure, and then impenetrable darkness again. After this all but instantaneous view he has to write a treatise on the building of the cathedral, the history of its architecture, and the arrangement of its chancels, a description of its frescos, and an orderly explanation of all the ecclesiastical paraphernalia. In the concluding chapter of his memoir he will be expected to tell something about the purpose and the ultimate destiny of it all. This is at best but a pitifully inadequate illustration of man during the brief space of civilization, looking skyward and trying to write the life history of the universe. What is it within him that makes it possible at all for him to be concerned with an order of such vast dimensions in space and in time? In comparison with the duration of a single star he might all but reason himself out of existence were it not that he must account for his consciousness of this bewildering environment. In addition to the limitation of time in which man's consciousness can work we cannot overemphasize some of the limitations in his ability to come in contact with the external world.

In the ordinary affairs of life man comes in contact with his environment through five distinct senses of perception whereby he can gain information of the things about him. In seeking information concerning

the starry universe, however, he is greatly handicapped by being entirely dependent upon only one of his five senses—the sense of sight. All the knowledge that we get of the stars must come through the sole medium of light; without sight man would never have become aware of the existence of any objects outside the earth. Astronomy would have been impossible. Even so we should reflect that the stars undoubtedly give out much information which it is entirely impossible for us to gain because our eyes are limited to perception in a very limited part of the spectrum. The whole visible spectrum, extending from the violet to the red, is but a small portion of a vast and, for the most part, invisible spectrum of radiation of all sorts of wave lengths. We are made aware of this by numerous laboratory demonstrations. Through artificial contrivances man has been able to photograph wave lengths many times shorter than the bluest light visible to the eye. X-ray radiations give a band of wave lengths far too short for the human eye to perceive, and are studied because of their reactions on sensitive photographic plates. Shorter than the radiations of X-rays are some of the radiations from radium emanations. The cosmic rays newly discovered by Millikan represent even far shorter wave lengths than those emitted in the X-ray spectrum. Looking to the other end of the spectrum we find that beyond the reddest rays to which the human eye is sensitive there are many radiations of longer wave lengths perceived by specially treated photographic plates and cunningly devised electric apparatus, such as the bolometer and the

thermocouple. For still longer radiations such as the heat rays we have some perception through the sensory organs. Far out beyond the longest heat waves we find in turn the electromagnetic radiations of the radio broadcast stations, extending to wave lengths of 20,000 meters and upward. Thus we see there is in reality one long continuous spectrum extending from the shortest possible waves emitted by the cosmic rays on the one hand to the longest wireless radiations on the other. All of these waves are electromagnetic phenomena and rightly belong in the same sequence.

The shortest visible wave lengths are just about twice the frequency of the longest red waves to which the eye is sensitive. Taking an analogy from sound, this corresponds to about a single octave. If the length of the visible spectrum were to be represented by the length of this page, the entire electromagnetic spectrum would require a page of thirty thousand miles long.

All of our knowledge of the stars must come to us practically through the octave of the visible spectrum since because of the selective absorption by the atmosphere of the earth, little outside of the rays of the visible spectrum can penetrate. How handicapped we should be in trying to interpret the music of an orchestra were our perception limited to a single high pitched octave.

To carry our musical analogy a little further, suppose we were to handicap ourselves in attempting to appreciate the significance of a symphony by having only

the single sense of sight with which to seek information from the stellar universe. Imagine if you will a scientific individual with no sense of hearing attending a symphony under such circumstances. He would have a certain amount of interest in the gymnastics of the players and, since he is scientifically inclined, he would become sufficiently interested to attempt an analysis of music on the basis of information available through his remaining senses. He would devise all sorts of contrivances whereby he could measure the vibration of the strings of the various stringed instruments; he would calculate their wave lengths, and develop the necessary mathematical equations for the solution of various problems in wave mechanics. His interest would then lead him to an analysis of the puffs of air emitted by the various wood-wind and brass pieces. These he would discover were longitudinal waves in the air. A discussion of them would fill the pages of a second volume. Then his attention might well be turned to the traps and percussion instruments of the conventional orchestra. At the end of a long life of strenuous effort he would have achieved an enviable reputation as a recognized master in his profession in the technique of orchestral performance. Satisfied that he has learned about all that can be learned about music, perhaps somewhat bored with continued attendance at symphonic performances, he is invited once more to attend the production of a great symphony. Reluctantly he attends. Imagine that, by some strange circumstance, in the midst of the performance he suddenly acquires normal hearing.

What are his reactions? I can well fancy that in spite of the several volumes of treatises on the subject of strings, wood-wind, brass, and percussion instruments he has forgotten completely the technique of the production and for the first time in his life is lost in the rapture of what it is all about. He realizes that there is nothing wrong with the work which he has performed; his mathematics on wave motion still stands as a true representation of the mechanics of the situation, and yet he realizes how hopelessly inadequate was all that he had written so far as the true representation of the meaning of an orchestra is concerned.

Limited to only the sense of sight, man has analyzed for centuries the music of the skies. However true and accurate his conclusions, what he has learned must be as inadequate in expressing the meaning of the universe as would a treatise on wave motion in conveying the spirit of a Beethoven symphony.

CHAPTER XII

Surveying the Universe

NEARLY everyone has experienced the sensation of driving along the highway some Sunday morning and noting the sound of a church bell. As the car speedily approaches the source of sound, the pitch of the bell seems to rise in anticipation, perhaps, of a small increment in the congregation as a result of the approaching car. However, the car passes swiftly by on other pursuits, and we note a sudden fall in the pitch of the clanging bell, as anticipation has given way to disappointment. Of course to the bystander beneath the belfry, unmoved by the exciting ride of the Sunday morning venture, the bell has been clanging away all the while in its usual monotone. The change in the pitch of the bell upward on approaching and downward on receding from the source of sound is an exhibition of a phenomenon commonly known in physics as the Doppler effect. What happens is that as the ear rapidly approaches the sound waves sent out from a ringing bell more waves crowd into the ear per second than is the normal output of the mechanism. The effect is precisely the same as though a bell of higher frequency were sounding. In receding from the source we are literally running away from the

church bell and receive fewer vibrations or sound waves per second than is normal, and the pitch is therefore lower, as though a heavier bell of lower frequency were sounding. What is true of sound applies equally well to waves of light. If a star is approaching the earth, or what amounts to the same thing, for practical purposes, if an observer on the earth is approaching a star, any particular wave length broadcast by that star, such as from the vibrations of an atom of hydrogen, will apparently be shortened because the moving observer will receive more than the normal number of vibrations per second. This apparently shortened wave will then traverse the prism of the spectroscope, be bent at a slightly greater angle, and give us a line in the spectrum somewhat displaced toward the blue from what would have been its normal position. The amount by which the line is displaced toward the blue is the index of the speed existing between the observer and the source. In a similar way, if the observer is receding from a star, or a star is receding from the earth, there will be a corresponding displacement of each line in the spectrum toward the red. In this case the effective wave lengths are apparently increased as the observer speeds merrily away from the source. Thus, the spectroscope, in addition to analyzing the light of the stars and telling us something of their chemical and visible constitution, has made possible the determination of the motions of the stars to or from the earth.

The application of this principle of Doppler's to astronomy was first made by Vogel in 1888 and opened

up a whole new field for astronomical investigation—the determination of so-called radial velocities of stars. We recall that Herschel had discovered that stars slowly drift across the line of sight in the passing years, each in its own peculiar way, in the course of time distorting slightly the age-old constellations. This crosswise movement of the stars around the sky was frequently spoken of as "proper motion." In contradistinction to proper motion, radial velocity describes the motion of a star along the line of sight from the observer to the star. Again in contrast to the determination of proper motion, it is not necessary to wait for long intervals to determine radial velocity. This is the great advantage of the spectroscope. If a star is moving toward us a single photograph of its spectrum will exhibit all the lines displaced toward the blue. The amount of the displacement may be quantitatively measured by means of the microscope. A little mathematical calculation based on this displacement will give the actual number of miles per second at which the star is approaching the earth. This new method of detecting motion disclosed almost at the outset the systematic approach and recession of the earth to and from stars in certain parts of the sky, due to the fact that the earth was moving about the sun in its annual orbit. Thus the spectroscope gave another demonstration direct and positive that the earth traveled about the sun in an orbit of some 93,000,000 miles' radius at an average velocity of about 18 miles a second. Systematic programs for the measurement of radial velocity of all parts of the sky have been going on now for

more than 50 years. Careful analysis of the observations has brought to light many interesting facts. It has been found, for example, that in the spectra of most of the stars near the constellations Hercules and Lyra the lines are persistently displaced toward the blue which shows that the stars are approaching the earth irrespective of the time of year. In the directly opposite part of the sky, the region near the constellation of Orion, we find that by and large stars give spectra with lines consistently displaced toward the red, indicating they are receding from us with a velocity of about the same amount. In the girdle about the sky, midway between the points just mentioned, there is little tendency for a systematic shift of the lines either to the blue or to the red. What is to be the interpretation of all this newly acquired data? Offhand we might say that all the stars in the half of the sky toward Hercules and Lyra are coming toward us and those in the other half of the sky are running away from us, while we stand like a rock in midstream with the surrounding current rushing by. Once again, however, we are aware of the problem of relative motion and have learned all too well not to take the first interpretation of a fact at its face value. In reality we find ourselves moving through the stars toward the direction of Hercules and Lyra and away from the region in the opposite part of the sky represented by the constellation of Orion. What a happy vindication of Herschel's investigations of the proper motions of the stars. The spectroscope has approached the problem in an entirely new

way, based on principles unknown to Herschel, and has pointed to the same conclusion. Without decades of delay it has revealed that the sun is moving through space at the velocity of 12 miles per second, or 400,000,000 miles every year. It can tell us the general direction of space toward which we are at present moving and from which we have come; how long we may have been on this particular course and how long we shall continue we can hardly say.

It will be of interest, however, to attempt to throw out some sounding line from our moving ship and, by means of devices not known in Herschel's day, to determine the distances to some of the nearer and to some of the more remote stars. By sounding such depths we may be able to get a little better picture of the significance of our motion and our place in the universe.

We have seen that one of the problems of greatest difficulty confronting astronomers was that of being able to demonstrate the earth's motion around the sun by detecting the seasonal displacement of the stars which we have called parallax. While Herschel's attempts had been futile at determining this small angle of displacement, there came from his attempts at this discovery an interesting by-product, the discovery of the binary stars. But the main problem was still unsolved. It was Bessel who in the year 1839 successfully detected a systematic shift in the position of a faint star known as 61 Cygni. Thus, after three centuries of effort following Copernicus' promulgation of his theory, success was forthcoming. Shortly after,

a similar parallactic displacement was found in a bright star in the southern hemisphere, Alpha-Centauri. As first measured, the parallax of Alpha-Centauri appeared to be about 1 second of arc. This meant that the star was distant 200,000 times the distance of the earth from the sun. Modern observations have made the parallax of this star about three-quarters of a second of arc, pushing its distance to twenty-seven millions of millions of miles, and yet leaving it as probably the nearest known star.

Astronomers were beginning to find at last a scale for interstellar distances. The mile as a unit of distance was altogether too small to deal with distances of such magnitude. For interstellar spaces other units have been devised. The most readily appreciated of these is the light year. This is the distance which light, traveling at a velocity of 186,000 miles a second, will traverse in a year's time. Calculate it out for yourself if you like. 186,000 for every second, 60 seconds for every minute; 60 minutes for each hour; 24 hours for every day, and 365 days in the year—you have now the distance which light has travelled in one year! It takes 4½ years for light to get to us from this, the nearest of the fixed stars.

Refinements in methods of measuring minute angles soon made possible the determination of the parallaxes of many other stars. Today astronomers measure regularly the parallaxes of the stars to an order of accuracy of about one one-hundredth of a second of arc. Such quantity is equal to the angle subtended by the diameter of a quarter of a dollar 300 miles away!

Even so, the number of stars coming within the range of this method is painfully small when one considers the hundreds of millions of stars revealed by our modern telescopes. Parallax computation can determine the distance to only a few of the sun's nearest neighbors. Such a process is pitifully inadequate to begin to sound the depths of the Milky Way. When one tries to form a picture of the dimensions of the whole siderial structure which we call our galactic system we must resort to more subtle methods.

At strategic points along our coastline are many lighthouses. Some shine with a fixed intensity. Others flash in periodic fashion. Various combinations of flashes make the so-called characteristics for each particular light. Steaming along the shore the navigator learns to recognize these lights by their periodic flashes. Full information in regard to each light is contained in the official catalogues. These give the period and characteristics of the flash, the candle-power of the light, and its locality. From the information therein contained a comparison may be made with the flashes from distant lights rising above the horizon and their identity made certain.

About us in the sky are the lighthouses of space. Many of these shine with an apparently fixed illumination. Others notably and periodically vary in brightness. Among these so-called variable stars is one known as Delta Cephei. With all the regularity of a flashing beacon it rises and falls in brightness in a period of 5⅖ days. The apparent brightness of this star can be measured with photometers especially adapted to the

purpose. The parallax of this star has also been measured so that we know its distance. Knowing that the apparent intensity of a light varies inversely as the square of its distance from us, we can calculate its absolute brightness, or its candlepower. Other stars of this type, but with shorter and longer periods between flashes, have been observed, and the distances to these stars have likewise been measured.

Working over such data at the Harvard Observatory some years ago Miss Leavitt was able to note a characteristic relationship between the brightness of these so-called Cepheid variables and the periods between the flashes. So consistent did the relationship hold between the stars whose distance and brightness could be measured that it appeared reasonable to attempt to apply this period-luminosity law to the determination of the intrinsic brightness of similar variables in the remoter parts of space where no parallaxes could be determined. A new field for the application of such a method arose when Bailey, working at the Arequipa station of this observatory, discovered a large number of variables of this type in a very compact cluster of stars known as Omega Centauri. Working on this new principle, Shapley, then at the Mt. Wilson Observatory, undertook an extensive investigation of the variables in a large number of these globular clusters of stars, scattered here and there throughout the sky. By carefully determining the periods of the variation in brightness he calculated the absolute luminosity of those stars by means of this newly discovered period-luminosity law. Measuring

the apparent brightness of the stars as revealed on the plates taken at Mt. Wilson Observatory, he computed the distance to these distant suns on the supposition that their apparent faintness was due to the light varying inversely to the square of the distance. What inconceivable distances resulted! The great cluster in the constellation Hercules showed itself to be distant from us by no less than 60,000 light years. Another globular cluster, bearing the cryptic number NGC 7006, betrayed its distance as 180,000 light years. From an elaborate analysis of all such data available, Shapley came to the conclusion that the diameter of our galactic system was some 300,000 light years.

Thus we have seen a little of the universe of yesterday with its over-arching dome of luminous points evolve into a gigantic stellar system of some two or three billions of suns, many of them millions of times as big as our own, circulating about like bees in some huge swarm, forming a more or less definite watch-shaped figure of such dimensions that 300,000 years are gone before the light from a star can traverse once the diameter of this great cosmic whirlpool.

Well off from the center of such a system—perhaps half way from the center to the rim—is one small insignificant star of more importance to us than any other star in the whole galactic system. It is our sun. Around this sun circulate little grains of dust we call the planets. On one of these (less than one-millionth the size of the sun itself) tiny specks migrate here and there, moving hither and thither, jostling one another

as they go—the race of man. Through some strange mystic quality we call mind, man looks out into space as but for one brief moment, then writes his picture of the universe. Night after night his giant telescopes pierce the sky to add one new grain of truth. Scattered here and there among the stars, yet really far beyond, faint spiral nebulae reveal to him the exploring ground of other mysteries.

Within the last few years the big 100-inch mirror of the world's largest instrument has resolved many of these spirals into aggregations of stars. Among the stars of the most conspicuous one of these, the

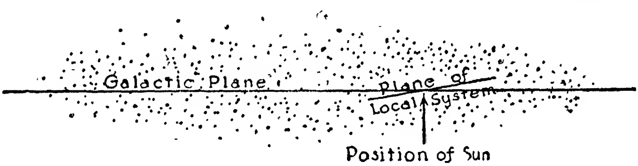

FIG. 18.—Diagram of the galactic system.

great nebula in Andromeda, Hubble discovered a variation in brightness which corresponded to the well-known flashes of the Cepheid-type variable stars. Timing the period between flashes the actual luminosity, or the intrinsic brightness, of these stars was determined. Painstaking photometric measurements of their faint images on the photographic plate yielded the apparent brightness of these objects seen at the enormous distance of the nebula from the earth. Once more assuming that light varies inversely as the square of the distance, the distance of the nebula was computed. It was 900,000 light years. As soon as its distance became known the actual dimensions of that mysteri-

Plate XV.—The great cluster in Hercules (Messier 13).

PLATE XVI.—Spiral nebula in Ursa Major (NGC 3031).

ous unknown object were revealed by the simplest sort of mathematical calculation. What is its diameter? Three thousand light years. It is a veritable universe in itself, of such vast extent that it takes light 3,000 years to pass from one side to the other of this great cosmic whirl. Further researches have revealed other spirals to be at distances even many times more remote. It has been recently estimated that a million of these spiral universes are scattered here and there through space.

CHAPTER XIII

Our Changing Sun

HAVING traced the changes in man's conception of the sky from the star-spangled dome of yesterday to a galactic system of a billion suns, we may well ask, what is the sun?

As the sun is the dominating object in the sky, giving light and heat and producing the changing seasons through its apparent movements, it is little wonder that it became an object of worship in Mediterranean civilization. In ancient mythology Apollo drove the sun-chariot across the sky. Occasional sun spots large enough to be seen with the naked eye were holes torn in the fabric of its surface now and then by the hoofs of the spirited stallions which hauled the dazzling float along its way. The Greek philosopher Anaxagoras was threatened with death and at length exiled for his pernicious views that the sun was only a ball of fire and equal in size to all Greece. Hardly different from the Hellenic picture is the Hebraic conception so naively described in the nineteenth Psalm:

> The sun is as a bridegroom coming out of his chamber
> Who rejoiceth as a strong man to run a race.
> His going forth is from the end of Heaven
> And his circuit unto the ends of it;
> And there is nothing hid from the heat thereof.

In contrast to such conceptions, which are poetic rather than scientific, we turn to what modern astronomy has to say.

While the sun is indeed a typical star, it is to us unlike all the rest of the stars in that its distance fortunately is not great as astronomical distances go. To be sure it is 93,000,000 miles away, but with the speed of a modern airplane a young babe might hope to get there in a lifetime were he destined to outlive an octogenarian. This neighborliness of the sun makes it possible for us to find out a great deal about its true nature. As to size it is somewhat more than a million times as big as the earth. It is about 300,000 times as massive. The mass of the earth, by the way, is 6,000,000,000,000,000,000,000 tons. In spite of what appears to be an enormous weight for the sun its huge bulk means that it must be for the most part exceedingly tenuous in its texture. It is indeed an exceedingly hot gaseous body. While the density of the matter at its core is undoubtedly very high, the density rapidly diminishes with increasing distance from the center. At the surface of the sun which we see, and call the photosphere, the gases must be a hundred times more rare than the rarest atmosphere overlying our loftiest mountains.

The temperature of the sun's surface is about 12,000° F. The temperature rises rapidly as we penetrate into the interior and according to Eddington is some 80,000,000° at the sun's center. We may picture the inside of the sun as a veritable hurly-burly of atoms and electrons, flying hither and thither at terrific velocities.

From this hot interior ultimately arises the source of solar radiation.

The amount of solar radiation received at the surface of the earth is definitely measurable. Could it be converted into mechanical energy, it would equal 1½ horsepower for every square yard directly exposed to the sun's rays. This means that the whole earth receives heat from the sun at such a rate that if the heat were put to work it would represent the equivalent of 230,000,000,000,000 horsepower! With the exception of a few experimental engines once set to work for irrigation purposes in arid regions, man has practically made no attempt to convert directly solar rays into mechanical effort. Perhaps when the oil supply runs low and coal is $100 a ton man may learn to tap profitably this abundant source. If we reflect further that the earth as a whole can intercept less than one-billionth of the sun's total output, we realize the more our complete inability to conceive of this stupendous and seemingly inexhaustible supply.

When we examine the sun's surface through the telescope, we find that it presents a strange mottled or granular appearance. In this mottled surface there develop now and then dark patches often growing into huge black areas surrounded by a somewhat shaded region called the penumbra. These dark areas are the sun spots. Whatever may be ultimately accepted as the best explanation of the spots, one cannot go far wrong in picturing a sun spot as a terrific storm in the sun's atmosphere, a cyclonic whirlwind for which the

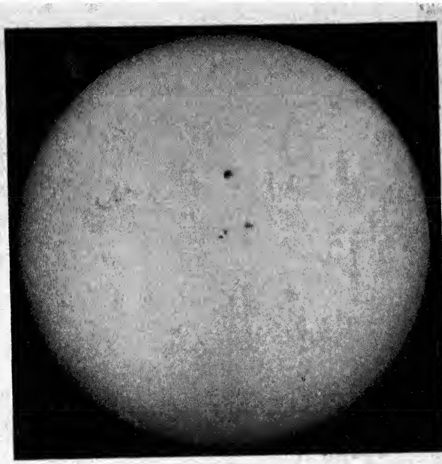

PLATE XVII.—The sun photographed at Perkins Observatory.

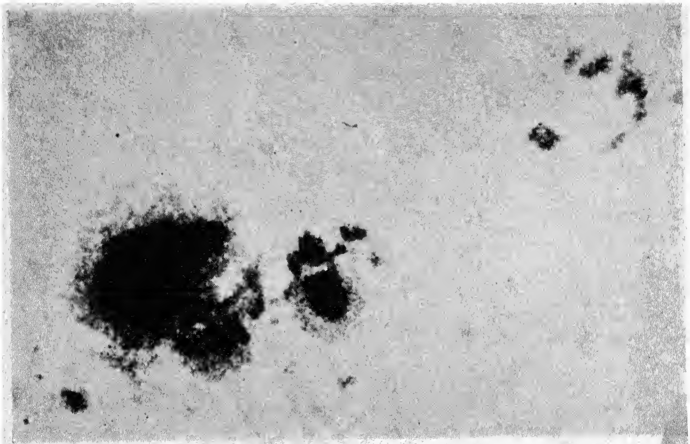

PLATE XVIII.—An enlarged view of a typical group of sun spots.

most violent tropical hurricane would be a microscopic illustration.

One of the most extraordinary features of sun spots is the periodicity with which they appear on the solar

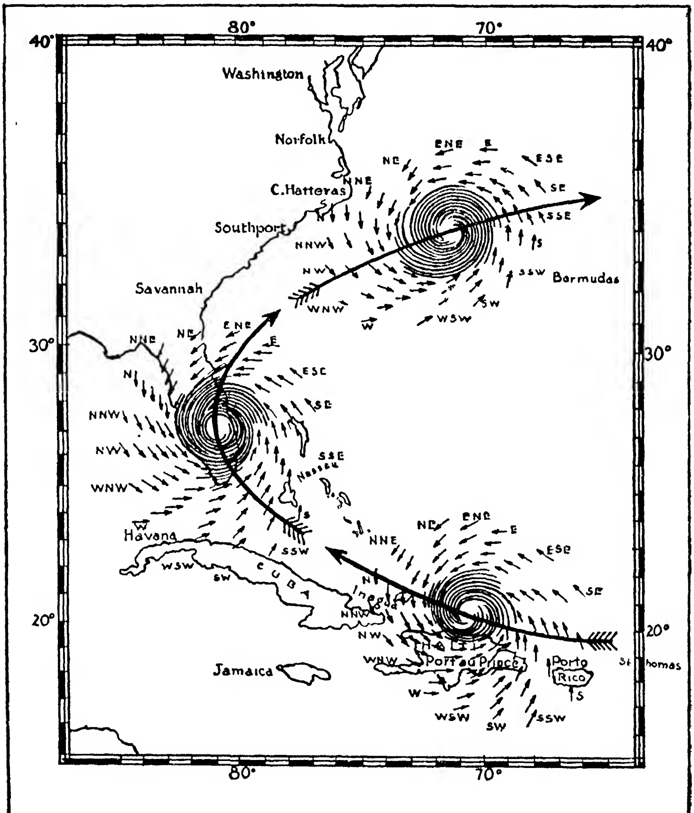

FIG. 19.—Tropical hurricanes are similar to solar vortices.

surface. For nearly a century and a half sufficiently accurate records of the appearance of sun spots have been made so that, if we plot the degree of spottedness

of the solar surface year by year, we discover a periodic rise and fall in the stormy condition of the sun's surface spanning approximately 11 years. We are now (1929) not far from what we call a sun-spot maximum. About 6 years ago sun spots were very scarce, and, when they occasionally appeared, were very small and insignificant affairs.

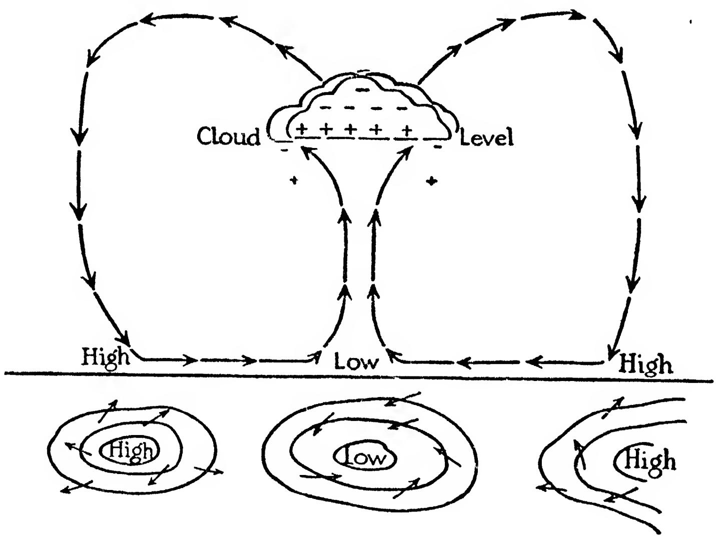

FIG. 20.—The formation of a thunderstorm "low" pressure area suggests the formation of a solar vortex.

Curiously enough, at the beginning of a sun-spot cycle the spots appear on the sun's surface at relatively high latitudes and as the cycle progresses they increase in size and number and break out at successively lower latitudes on the solar sphere, a given cycle of spots finally disappearing just a few degrees from the solar equator.

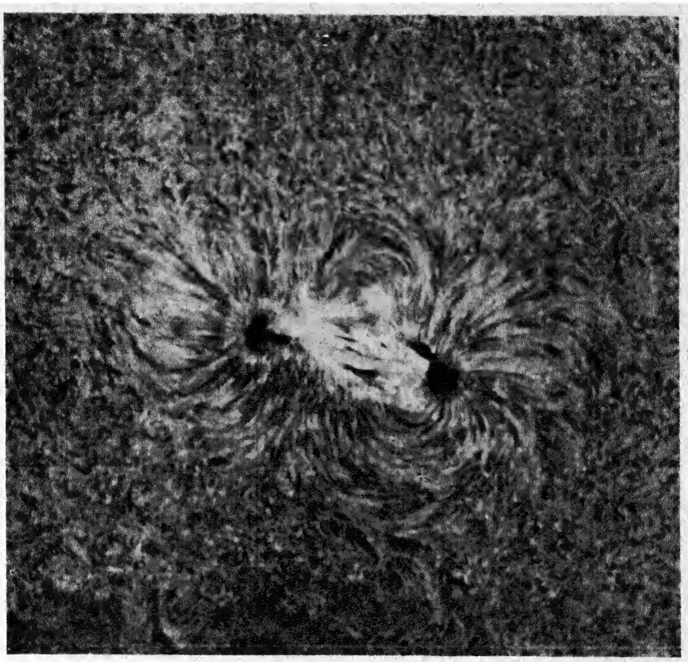

PLATE XIX.—Sun's surface showing solar vortices. (*Photographed at the Mount Wilson Observatory.*)

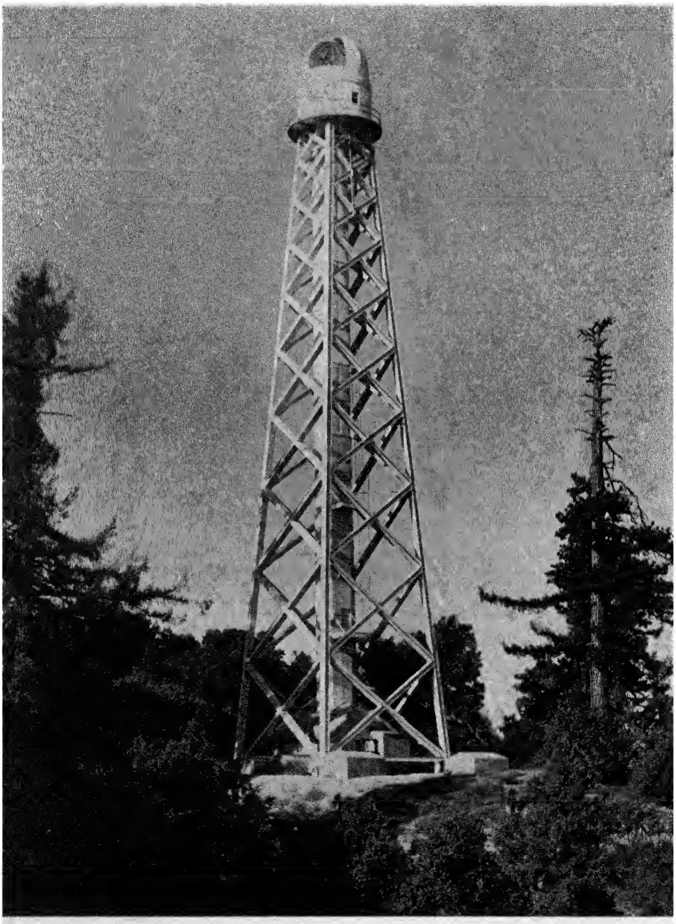

PLATE XX.—The solar tower at the Mount Wilson Observatory, California

The true character of sun spots as magnetic whirls in the solar atmosphere was first established by Hale of the Mount Wilson Observatory in 1908. By a special adaptation of the spectroscope, Hale was able to photograph different layers in the solar atmosphere and establish the existence of vortices similar to the whirlwinds which are characteristic of cyclonic storms in the earth's atmosphere. Furthermore, by analyzing the character of the rays of light radiating from the sun spots, Hale was able to demonstrate that the character of the light emitted from the center of these gigantic whirls betrayed unmistakably that they were the poles of powerful electromagnets.

With the reappearance of the last sun-spot cycle it was firmly established that the polarity of these spots completely reverses from one cycle to the next. It has been recently suggested by a Norwegian scientist, Bjerknes, that the sun spots are the visible ends of a tubular vortex which may extend east and west for great distances below the sun's surface. A reversal in the direction of whirl in this supposed vortex would account for a reversal of the magnetic polarity of the sun spots with the change of cycle.

No completely satisfactory explanation of the ultimate origin of these whirls has yet been made. There is one peculiarity, however, in the sun's behavior which doubtless has an important bearing on this point. While the sun rotates on its axis from west to east in common with the axial rotation of the other bodies in the solar system, its period of rotation is not the same for different parts of the solar surface. Near

the equator the sun rotates once on its axis in a period of 24.6 days, whereas in latitude 35° the motion of the spots across the surface indicates that 26.6 days are consumed in a single rotation. Spectroscopic observations make it possible to determine the rate of rotation in regions of higher latitudes than those in which the spots appear. In latitude 60° the rotation period is nearly 31 days. The continual slipping of the atmospheric layers of lower latitude past those of higher latitude must result in the formation of eddy currents favorable to the formation of cyclonic whirls, thus producing the sun spots.

The mention of sun spots invariably raises the question of a possible connection between the spots on the sun and terrestrial phenomena. Some statisticians with an insatiable appetite for correlations have attempted to connect with sun spots almost every cycle in world affairs from fluctuations in the New York stock market to the fecundity of rabbits in northern Canada. In the popular mind almost every world catastrophe has sooner or later been attributed to sun spots, from a Florida hurricane to the great World War, both of which, by the way, did culminate around a sun-spot maximum.

Leaving speculation aside there are to the scientist certain well recognized phenomena on the earth which pass through cycles whose correlation with the sun-spot cycle is unmistakable.

For more than a century and a half records of the numbers of sun spots have been kept and afford data for a study of their periodicity over a range of about

fifteen 11-year cycles. For more than a century records of the variation in the earth's magnetism have been made and preserved. The remarkable correlation of sun spots with magnetic changes on the earth is at

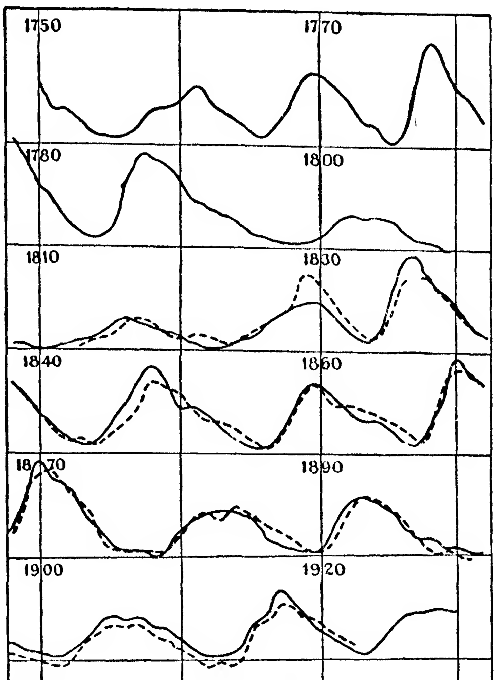

Fig. 21.—Sun-spot numbers and magnetic effects. The full-line curve represents relative sun-spot numbers; the dotted curve, corresponding changes in the earth's magnetic field.

once apparent from a glance at the accompanying graph. Simultaneously with the so-called magnetic storms, which are wont to sweep the earth upon the appearance of great sun-spot activity, we witness frequent and brilliant displays of the aurora borealis.

The auroral light is due to an electronic discharge in the upper and highly rarified atmosphere of the earth and is most probably activated by charged particles of electricity emanating from the sun whose activity varies with the sun-spot cycle. It seems probable that the magnetic vortical whirl of a sun spot acts as a directing field in guiding electrons escaping from the sun. When a conspicuous spot appears near the center of the solar disk, and is therefore approximately in line with the earth and the sun's center, there is a particularly good chance of the ejected electrons striking the earth's atmosphere and causing an ionization or electrification of the upper atmosphere giving rise to an auroral display. At the same time the induced earth currents will distort the earth's magnetic field causing the small variations in the compass needle so characteristic of a "magnetic storm."

While for many generations scientists have recognized the recurrent cycle in solar activity and the magnetic changes in the earth, never before the present period of sun-spot activity has it been possible to study so thoroughly the changing degree of electrification in the earth's atmosphere with the coming and going of the spots across the solar disk. All this has come about by the development of radio.

The general correlation of radio reception with sun spots during a portion of the year 1926 is shown in Fig. 22. The full-line curve is traced as the mean of north Atlantic, south Atlantic, and continental reception, covering wave lengths from 33 to 20,000 meters. The dotted curve is the inverted curve of the so-

called Wolfer sun-spot numbers. These numbers are based upon the number of spots visible on the sun's surface at a given time and to some extent upon their area, but do not take into account the position of the spot on the sun's disk. The general run of the curve indicates that radio reception is distinctly impaired by an increase in the sun-spot numbers.

Quantitative measurements of radio reception since 1926 seem to have established beyond much doubt that night reception in the broadcast zone is in general poor when sun spots are numerous, and good when the

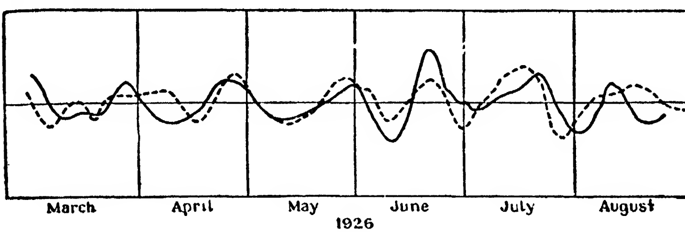

Fig. 22.—Sun-spots affect radio reception. The full-line curve represents reversed sun-spot numbers; the dotted curve, relative strength of radio signals.

spots are few. The quantitative measurement of radio reception was begun by Mr. G. W. Pickard in his private laboratory at Newton Centre in February, 1926. In February, 1928, a duplicate set of apparatus was installed at the Astronomical Laboratory at Harvard University and the measurements were carried on there under the direction of the author. Simultaneous records made for a short time at both receiving stations gave the necessary reduction factor for rendering these two series of observations comparable. The investigations at the Newton Centre

laboratory were then shifted from the broadcast zone to the region of 18 kilocycles.

Every night shortly before 9 P. M. Eastern Standard Time, Sundays and holidays included, down in a small secluded room in the basement of the Harvard Astronomical Laboratory in Massachusetts and at the Perkins Observatory in Delaware, Ohio, an attendant tunes in on WBBM at 770 kilocycles. Not trusting his own impressions as to whether reception is excellent, good, fair, or poor, he closes the key to the automatic recorder, whose slender pen with an impersonal but almost uncanny intelligence writes a continuous record of the intensity of the incoming waves. It is with utter disregard for astronomical or electrical theories that it leaves its unprejudiced and indelible record of what happens for the scientist to analyze.

Plate XXI is a photograph of the installation in the research room at the Perkins Observatory. The self-recording galvanometer is shown immediately beside the electric desk lamp and the local oscillator for standardizing the receiver before each night's record is shown on the stand at the extreme left.

In addition to the measurement of radio reception the sun is photographed at the Perkins Observatory and the Harvard Laboratory every clear day in cooperation with the Yerkes, Mount Wilson, and Naval Observatories, and a careful study made of the size, numbers, and location of the sun spots. It is believed from a preliminary study that the distance of the spots from the center of the disk, or the sun-earth line, is an important factor in the study of correlation of sun

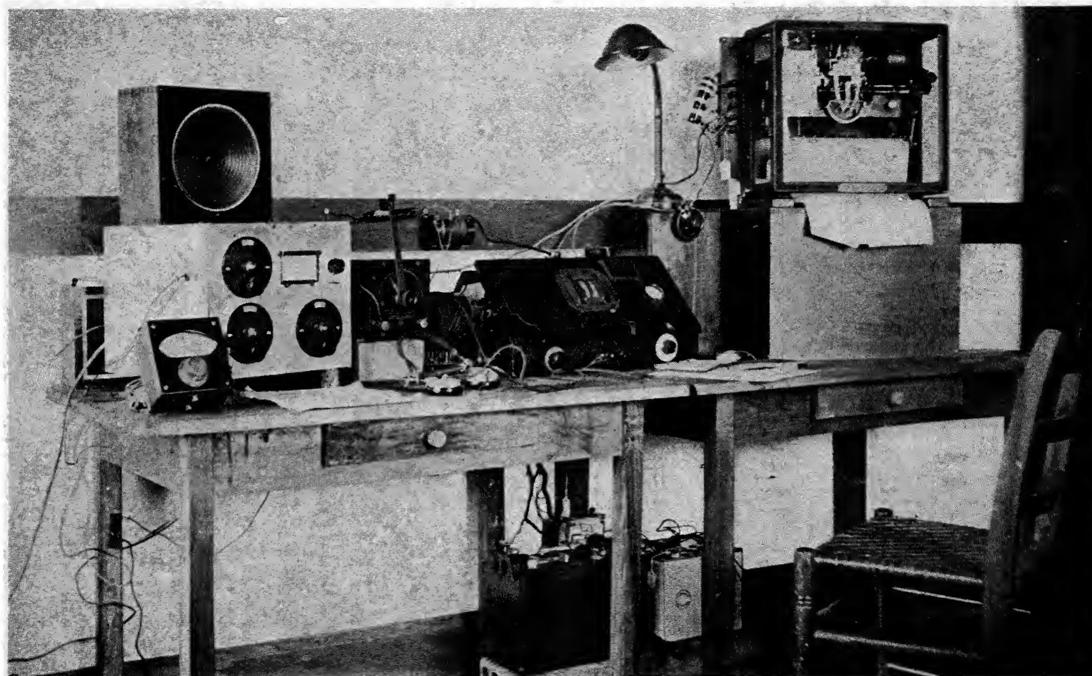

PLATE XXI.—Apparatus for automatically recording radio intensities at Perkins Observatory.

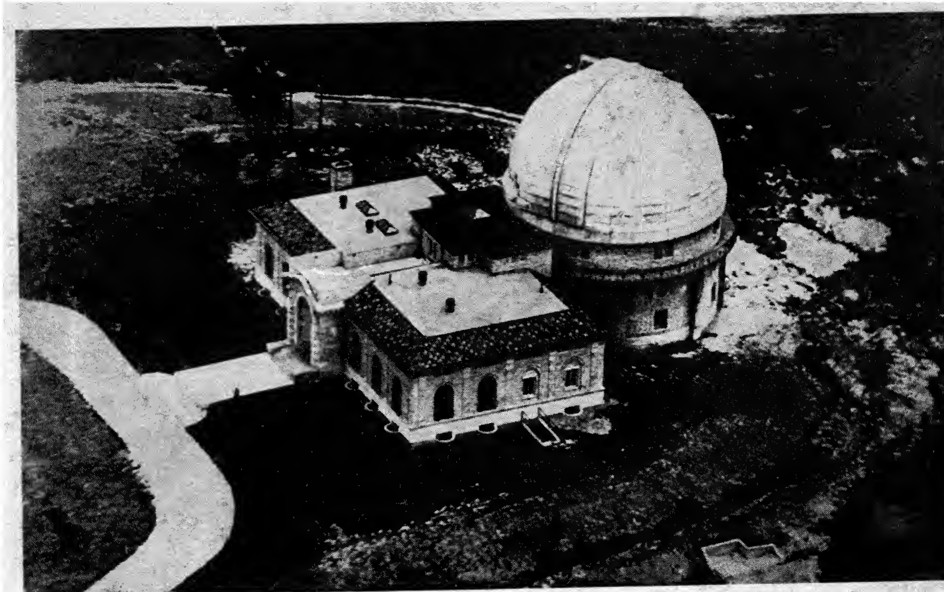

Plate XXII.—The Perkins Observatory, Delaware, Ohio, where observations of solar activity and radio reception are being made. The large dome houses the new 69-inch reflecting telescope, the third largest in the world.

spots with radio reception and other electromagnetic phenomena on the earth.

It is in the reduction and analysis of these records that the startling discovery of the effect of sun spots on radio has become established.

The apparatus employed is a superheterodyne receiver especially constructed for the purpose and feeding into a self-recording galvanometer which registers in microvolts in the antenna the strength of the carrier wave received from the broadcasting station of WBBM, Chicago. The apparatus is so designed that the modulations of the carrier wave do not affect the record appreciably and the results obtained are independent of the nature of the program broadcast. Realizing the importance of the investigation, the broadcasting station scrupulously maintains a constant energy output in its antenna current, and each night before the radio observers begin work the receiving set is carefully calibrated by means of a small, local oscillator in the laboratory placed in close proximity to the receiving set. The output of the local oscillator necessary to maintain full-scale deflection upon the galvanometer of the receiver is then read from the microammeter in the circuit, and the constant of the apparatus for the evening is thus determined. In this way local sources of error both at the broadcasting and at the receiving ends are eliminated, and the resulting measures of the variable reception from night to night may be attributed to the changing electrical conditions of the atmosphere through which

the broadcast wave travels enroute from Chicago to the observer.

Scientists differ in their ideas as to just what happens when a broadcast wave travels over the earth. Some believe that an ether wave is propagated which is reflected back to earth from an ionized layer of the earth's atmosphere known as the Kennelly-Heaviside layer which lies some 70 kilometers above the earth's surface. Others maintain that the electric wave is refracted rather than reflected from such a layer. Whatever the mechanism, the wave appears to be turned back by this ionized layer of the earth's atmosphere. Any change in the intensity or degree of this ionization or electrification of the earth's upper atmosphere would have the effect of bending the ray more abruptly or less abruptly toward the earth and thereupon at once be noticed in the intensity of radio reception. The more rapid changes of this sort are doubtless responsible for the phenomena of fading, with which every radio fan is thoroughly familiar. According to our theory the sun constantly bombards the earth's atmosphere with electrons or bundles of energy of high frequency which in turn tear apart the positive and negative charges of the atmospheric molecules, in other words, ionize it to a very considerable extent, thus producing the Kennelly-Heaviside layer. If the sun is more active on occasion, as when large spots appear on its surface, the degree of ionization increases, producing substantially the effect of lowering the Kennelly-Heaviside layer and upsetting the radio reception. When the sun is again

less active, the atmosphere tends to return to its normal state of ionization and the radio broadcasting reception tends to improve as the ionized layer lifts.

For certain wave lengths it is possible that the effect of a rising and falling ionized layer may actually be the reverse of that noted in the broadcasting zone, giving improved reception during greater solar activity and poorer reception during less solar activity.

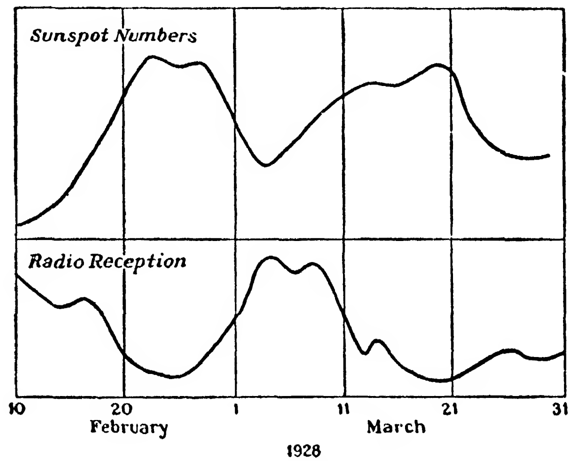

FIG. 23.—Radio reception and sun-spot records for two typical months.

Curiously enough this is just what has been observed by Dr. Pickard at the Newton Centre laboratory when working on long waves of 18-kilocycle frequency.

How closely the changes in this ionized layer, as tested by radio reception, actually conform with solar activity as exhibited by the numbers and size of spots is well illustrated in the adjacent Fig. 23, where the upper curve shows the relative sun-spot numbers of February and March, 1928, and the lower curve

represents the corresponding changes in intensity of the received radio waves. The inverse relation between the two is clearly marked. There is also represented

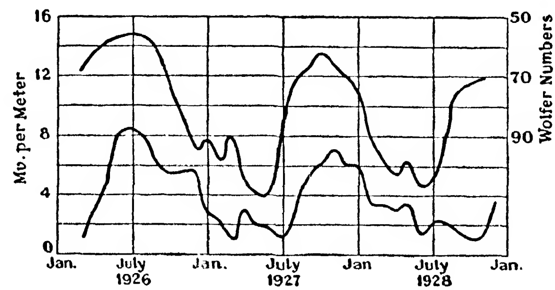

FIG. 24.—Radio reception for 1926 to 1928. The upper curve is the inverted curve of sun-spot numbers. The lower curve is the strength of radio signals measured in microvolts.

the record for the entire time since these researches have been in progress. In this case the sun-spot curve has been inverted to show more closely the inverse relationship. It will be noted there have occurred

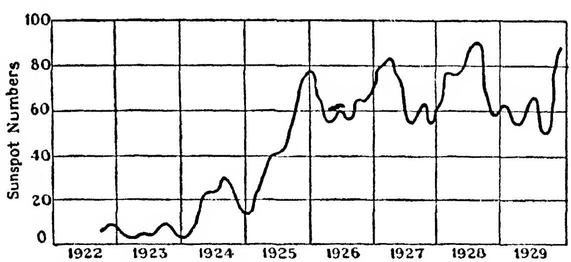

FIG. 25.—The sun-spot cycle for 1922 to 1929 shows a 15-month secondary fluctuation.

rather sharp maxima and minima at an interval of approximately 15 months. If we look at the complete record of sun-spot numbers from the last minimum in 1923, it will be observed that this 15-month interval

between maxima and minima appears to persist throughout the whole record. It is a matter of no little interest that the rapid development of radio broad-casting began about 1923 near the sun-spot minimum and therefore at no time since has radio reception been so favorable, nor is it likely that equally good receiving conditions will return until the present sun-spot cycle terminates in 1934.

CHAPTER XIV

Sun Spots and the Earth

THE astronomer is often asked, "Is there any connection between sun spots and the weather?" It is with considerable hesitancy that the scientist makes any statement concerning astronomical phenomena and weather changes. Fundamentally the sun is directly responsible for all our weather. The inequalities of day and night in different parts of the globe, the overheating of the tropics and continental areas, with the resulting areas of high and low atmospheric pressure, give rise to convection currents and surface winds which are responsible for the many caprices of the weather. If changes in solar activity were sufficient in amount and long enough in duration, our normal run of weather might be seriously modified.

Some variation in the output of solar heat which follows rather closely the sun-spot cycle appears to have been well established by Abbot of the Smithsonian Institution. Through careful measurements of solar radiation extending over a period of many years, Abbot has come to the conclusion that during a sun-spot maximum the earth receives on the whole about 2 per cent more than the normal radiation, whereas during a sun-spot minimum the radiation received by

the earth falls below the normal amount by a corresponding percentage. This is not to be interpreted, however, as meaning that in a definite locality the weather will be warmer at sun-spot maximum than at sun-spot minimum. In fact there is considerable evidence to support the contention that the opposite is more often the case. Lower surface temperatures are not necessarily inconsistent with increased solar radiation as measured by Abbot with the pyrheliometer.

It seems not unreasonable to suppose that, during the sun-spot maxima when the earth receives more radiation, the increased heat induces increased evaporation. Increased evaporation in turn leads to increased cloudiness and precipitation. This may very well result in actually lowering the air temperatures in many localities where our meteorological data are gathered.

Some authorities have contended that there is a definite relation between precipitation on the earth and the appearance of sun spots. Recent researches of world weather records appear to indicate that there is unquestionably a periodic variation in precipitation over the earth as a whole, but investigations at present do not indicate that this is any simple function of the sun-spot cycle. It appears likely that we shall need more knowledge of the migrations of storms and their origin before precipitation data can be properly segregated for a more satisfactory study of precipitation and sun-spot correlation.

One of the most interesting researches bearing upon this problem is that of Prof. A. E. Douglas of the

University of Arizona. For many years Professor Douglas has been tracing the growth of very old trees by counting the rings and observing the spaces between rings in the cross-sections of tree trunks. The results of his study show the same characteristic 11-year cycle in the growth of trees which is so persistent in the activity of the sun. Trees undoubtedly grow more rapidly in years of greater temperature and precipitation and it may very well be that the redwoods of California and other ancient trees have carefully preserved for us the oldest records of sun-spot activity.

Studies in radio reception may yet prove one of the most profitable fields of research for untangling the puzzling relationships between solar and terrestrial phenomena. The fact that reception appears to vary with meteorological conditions and at the same time has been shown to depend in a large measure upon solar activity would suggest that, when we understand more fully the variables involved, we should be able to discover a more intimate connection between sun spots and weather than has heretofore been supposed.

An additional demonstration of the effect of changing sun-spot activity on the electrical field in space is found in the changing shape of the solar corona as observed at total solar eclipses occurring at various times with respect to the sun-spot cycle. The two illustrations will show the vast difference in the corona as photographed at time of sun-spot maximum as compared with that at sun-spot minimum. The corona typical of sun-spot minimum is invariably extended in

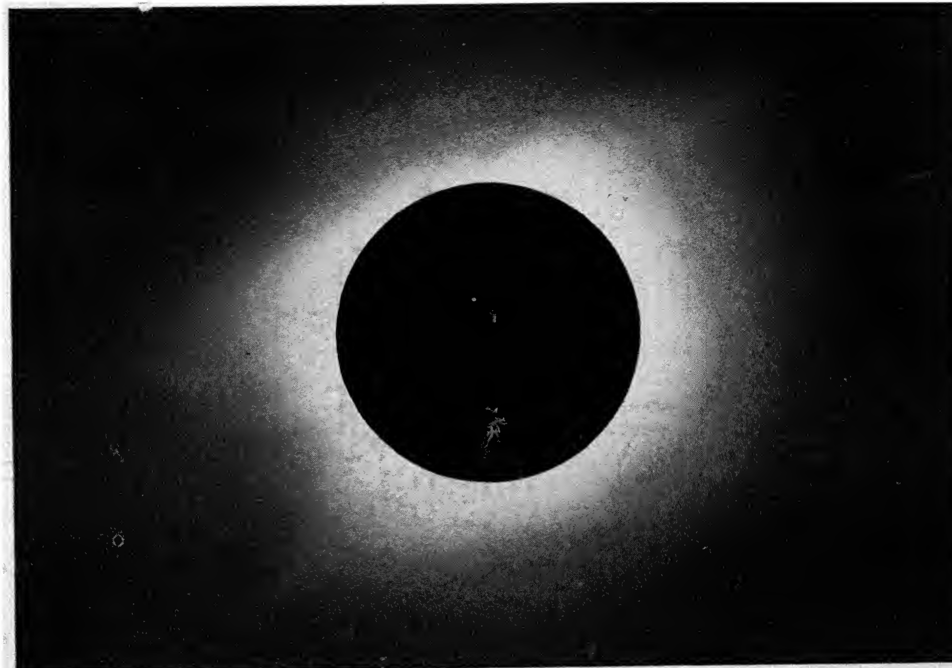

PLATE XXIII.—Solar corona at sun-spot minimum, Wallal, Australia, 1922. (*Lick Observatory.*)

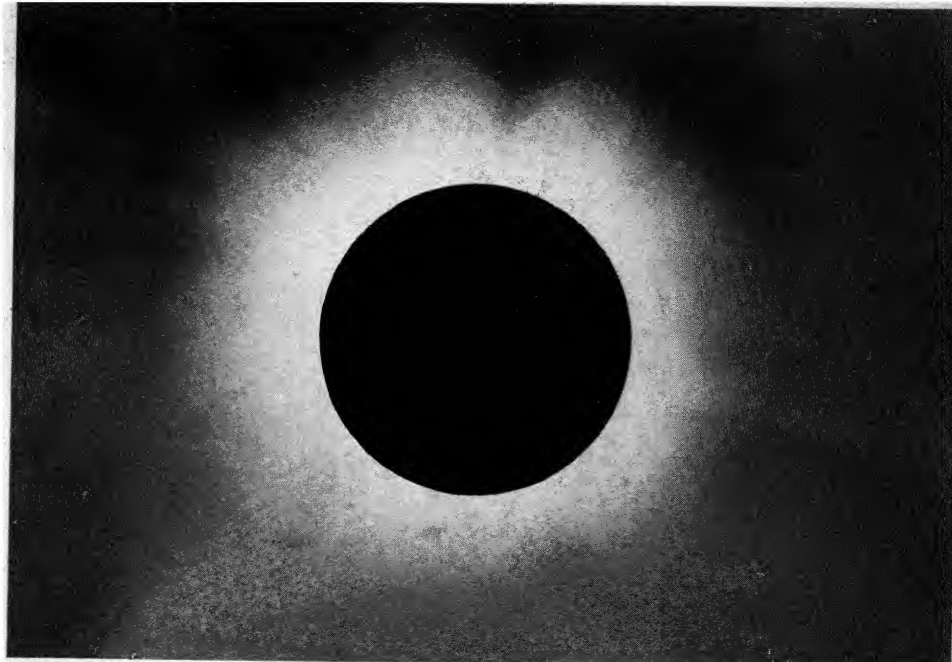

PLATE XXIV.—Solar corona near sun-spot maximum, Sumatra, 1926. (*Swarthmore Expedition.*)

the equatorial plane of the sun and is more often marked by extensive streamers, whereas at sun-spot maximum the corona takes on a more symmetrical appearance, the illumination extending in a much more uniform manner around the entire disk including the sun's poles.

Measures at many eclipses have already shown that the brightness of the solar corona appears to vary from eclipse to eclipse, and it seems probable that there is a distinct increase in the intensity at times of sun-spot maxima. It is for this reason, therefore, that astronomers have been particularly interested in photometric measures of the radiation from the solar corona during eclipses of the sun. As it is only at times of a total solar eclipse when the moon, coming between the sun and the earth, completely obscures the bright solar disk that the corona is at all visible, it is only at comparatively rare intervals and through rather extensive travels that any considerable body of data concerning the corona can be obtained. The results of the photometric measurements of the coronal light by the Harvard Expedition to Sumatra in 1926 seemed to indicate that the illumination was about 40 per cent greater than was indicated by the measures of coronal brightness at the eclipse in New England in 1925. In comparing coronal brightness from one eclipse to another, it is necessary to take into account the relative duration of the phase of totality before intercomparisons can be made. The reason for this becomes obvious when we reflect that an eclipse of short duration is occasioned when the moon is at a major distance from

the earth and therefore of such an apparent diameter that it barely covers the sun. This allows the innermost part of the corona to exhibit its light in our sky, and astronomers are aware that, whatever be the law of variation in brightness, most of the light comes from the so-called inner corona. During a long eclipse, however, the moon is relatively nearer the earth, its apparent diameter in the sky is greater, and not only is the sun more completely covered but a portion of the inner corona itself is obscured by the lunar disk. This means that even if the corona itself were to emit a constant light, we should find that eclipses of short duration were accompanied by coronae of relatively greater illumination. The eclipse of 1927 visible in England and Norway gave opportunity for studying the illumination under such circumstances.

Our party and instruments on this occasion cooperated with the McCormick-Chaloner Expedition of the Smithsonian Institution located at Fagernes, Norway. Adverse weather conditions, however, prevented any satisfactory observations. Nevertheless, our photometric apparatus was put into action throughout the eclipse and measures with the illuminometer, in spite of clouds, gave us a rough idea that the eclipse was a considerably brighter one than the Sumatra eclipse of 1926. If this eclipse had occurred under favorable skies, we might have secured sufficiently accurate data to combine with other eclipse data and to evaluate the percentage of increased brightness, owing to the fact that so much more of the inner corona was uncovered than was the case in the two previous eclipses.

It seems reasonable to expect, however, that after due corrections for duration of totality are applied we shall find that a higher intensity of the coronal light accompanies a period of sun-spot activity. This would appear to be substantiated by our measures of the eclipse of Sumatra in 1926, which was over 3 minutes' duration and was observed to be considerably brighter than the eclipse of 1925 which lasted only a little over 2 minutes.

As I write this I am returning from an expedition to Malaya where we observed the total eclipse of May 9, 1929. While light cirrus clouds interfered somewhat with the observations, our party was able to secure photometric measures which it is believed will add data of some value to the problem in question. The eclipse was unusually long, totality being of almost 5 minutes' duration. Preliminary results indicate, however, that the total illumination was a little greater than that of the Sumatra eclipse of 1926. Allowing for the greater obscuration of the inner corona on account of the relatively larger size of the moon's apparent diameter, it seems fair to suppose that we have here some additional evidence for an increase in the coronal brightness accompanying increased solar activity.

The accumulation of data during solar eclipses is painfully slow, and yet changes in the activity of the corona may give us at length an important clew to the effect of sun spots on the field of space immediately surrounding the sun. Whatever may be the nature of the solar corona, it seems certain that a portion of its illumination is produced by an electronic bombard-

ment from the highly heated gaseous surface of the solar atmosphere. On the other hand, the facts that the spectrum of the corona exhibits a continuous background, and that a portion of the coronal light is invariably polarized, lead us to believe that a considerable amount of the light may be sunlight reflected from small particles surrounding the sun. These particles may remain suspended against gravity by reason of radiation pressure or of rotational velocity.

If it were possible to photograph the solar corona from distant space and could the exposure be prolonged for hours instead of seconds, we should possibly find that the outer corona is a cloud, exceedingly tenuous, and yet so vast in extent as to include the inner planets, the earth, and perhaps the whole solar system within its confines. Whether or not the solar corona is but a part of a very extended cloud of possibly cosmic dimensions we shall leave to the next chapter to speculate.

It seems reasonable to suppose that further investigations of the corona may yet lead us to a knowledge of changes in the solar envelope that shall have an important bearing on the interpretation in solar and terrestrial phenomena. Any changes in solar radiation must ultimately affect the earth, for it is in the radiation of the sun that we literally "live and move and have our being."

CHAPTER XV

Cosmic Clouds

ON AN adjacent page is a photograph of one of the dark spots in the Milky Way. When Herschel first picked up this region with his telescope and was aware of the sparsity of stars within it, he exclaimed "Mein Gott, da ist ein Loch im Himmel" (My God, there is a hole in the sky). In these apparently empty spaces Herschel believed he was looking out through our universe into the vacant recesses of space, far, far beyond the stars.

When Barnard, at the Yerkes Observatory a little more than a decade ago, was making his photographs of the Milky Way, he unearthed, or rather unheavened, a great many such regions. The more he studied his photographs the more firmly he became convinced that these dark regions in many cases were to be interpreted not as vacant spots devoid of stars but rather as dark patches of obscuring matter cutting off completely the light of the luminous stars beyond. It was the old problem of relativity again. This time it was not a question of relativity of motion, but a question of the relativity of background. I remember well the skepticism that prevailed at the promulgation of this heretical viewpoint. However, Barnard persisted

in maintaining his interpretation, and carried on with his photographic program. His accumulating photographic plates probably did more than anything he wrote about them to build up confidence in his newly propounded theory.

Today the existence of large obscuring masses in the Milky Way, and the existence of dark matter bordering many diffuse luminous nebulae is scarcely doubted. Other galaxies, such as the great nebula in Andromeda, reveal vast stretches of dark matter entangled in their spiral whirls, engulfing stars and obstructing them. Is it possible that in our own stellar universe our sun may now be in the midst of some such cloud, or can we be assured that while many other suns may be embedded in such murkiness our own is quite immune and we look skyward from our earth with the confidence that we see the stars through uncluttered space? This is indeed a most vital question, for many of our estimates of distance to the remoter objects of our universe depend upon the assurance that light from those distant regions does not suffer diminution through traversing such enormous distances.

Many experiments have been made bearing on the problem. If the hypothetical ether which bears the light waves were a material, homogeneous substance like water or air, then it should absorb some of the light traversing it. In consequence, like water or air, it should slightly disperse the light in accordance with its wave length, and therefore blue light should travel somewhat faster than red or yellow light as it comes to

PLATE XXV.—Star cloud in Sagittarius showing dark nebulosity in the region of the Milky Way.

PLATE XXVI.—Spiral nebula in Virgo showing dark absorbing matter. (NGC 4594, *Mount Wilson Observatory.*)

us from a distant star. Fortunately this is easily tested by photographing the variations in the brightness of well-known variable stars in blue and yellow light simultaneously. Results show that there is no perceptible difference in the times of arrival of the blue and yellow light, even over extraordinary distances. Thus we may safely dismiss the question of absorption of light by the ether as more imaginary than real, a phrase probably quite as applicable to the ether itself.

The question of the dimming of the distant stars by particles of dark obscuring matter is an entirely different affair. The obscuring power of a given amount (mass) of material varies greatly with the size of the particles of which it is composed. The smaller the particles, down to a certain limit, the greater will be the obscuring power, the maximum occurring when the finely divided particles are about a hundred-thousandth of an inch in diameter, or of the order of the wave length of light. Thereafter as the particles become smaller they rapidly lose their power of stopping light. An astonishingly small amount of finely divided dust, such as smoke for example, can produce a vast amount of dimming. Russell points out that a layer of dust containing only a tenth of a milligram for each square centimeter would be completely opaque, no matter what its thickness, and on this basis the whole vast obscuring cloud in the constellation of Ophiuchus could be produced by a quantity of matter equal to hardly more than the amount of matter contained in a dozen of our suns.

Of course if the solar system were now in any such cloud we should see no stars at all. The fact that our vision of the universe is as good as it is indicates that the sun's immediate neighborhood is reasonably transparent. On the other hand there is evidence that space about us is not empty. The number of meteors falling to the earth is an indication of some of the larger lumps of cosmic material which abound in space and have presumably been captured by the solar system. It seems likely that a vast amount of such material from huge masses weighing tons down to the finest dust particles and gas molecules must be roaming at large in space until encountered and brought into local control by some passing star or planetary system. The existence of such cosmic clouds in the neighborhood of other stars gives rise to a certain amount of visible nebulosity where the light by which we photograph it appears to be reflected or excited from the nearby stars. A notable example of such a situation is to be found in the Pleiades.

If the solar system were in the edge of such a cloud, however tenuous, we should expect to see some of it illuminated in the immediate vicinity of the sun whenever the direct sunlight was obscured, as in the case of a solar eclipse. (Reference to this was made in closing the last chapter.) It seems reasonable to suppose that this may account for a large part of the coronal illumination, especially as regards the outer corona. In place of the structural details of the corona being produced by the particular way in which matter is thrown out from the sun, we should have on this

hypothesis the material particles already existing about the sun, and their visibility brought about by the streaming of electrons along paths more or less definitely defined by the sun's electric and magnetic fields. The tendency of the streamers when present to group themselves somewhat symmetrically about the magnetic pole of the sun is consistent with such an interpretation. The form of the corona would be quite dependent upon the degree of solar activity, which varies with the sun-spot cycle, but at the same time would be influenced by the general density and distribution of the surrounding particles.

Shortly after sunset, and as soon as twilight has vanished there is visible in the tropics a conspicuous glow of diffused light extending upward from the sunset point sometimes all the way to the zenith. At its greatest breadth it subtends an angle of thirty to forty degrees. It is the Zodiacal light. It may be seen in northern latitudes in the spring of the year after sunset or in the autumn before sunrise, although in neither case so conspicuously as in the tropics where its axis is more favorably situated with respect to the horizon. The usual explanation which has been offered for the phenomenon is that it is the reflection of sunlight from small meteoric particles circulating about the sun. It is appropriate to note that this phenomenon adds considerable support to the hypothesis of a circumsolar cloud.

A somewhat associated phenomenon is that of the *Gegenschein*, or counterglow. This is a faint patch of light rather definitely circular in shape which may be

seen under extremely favorable conditions at that point in the sky directly opposite the sun. The light is but a little more intense than that of the general sky illumination. It has been suggested that this too is the reflection of sunlight from small meteoric bodies at a considerable distance from the earth. In the theory of celestial mechanics there are dynamical grounds for suggesting this point as a rendezvous of meteoric material circulating about in the solar system. On the hypothesis of a spatial dust cloud it might be possible to account for such a patch of illumination as due to sunlight refracted into the earth's shadow by the shell of its atmosphere. The refraction of sunlight passing tangentially through the earth's atmosphere amounts to half a degree and would produce a luminous cone coming to a focus in space at a point 450,000 miles back of the earth. For a considerable distance inside this point a cloud of particles might be sufficiently illuminated to produce the observed effect.

Possibly a further argument for the existence of a circumsolar cloud is to be found in the behavior of comets' tails. It is common knowledge in astronomy that the tails of comets inevitably stream in a direction away from the sun. It has generally been supposed that all the material in the tail of a comet has been ejected from the head and borne away from the sun by the repulsive force of solar radiation. There is some difficulty, however, on such a hypothesis, in accounting for the radical shift in the direction of a comet's tail as it rounds the sun. In some instances where the comet passes the sun at a close range the tail must

Plate XXVII.—The zodiacal light as observed by the eclipse expedition to Malaya, 1929.

PLATE XXVIII.—The constellation of Orion showing surrounding nebulosity (*Mount Wilson Observatory.*)

whiff about through one hundred and eighty degrees in the space of a few hours. For material particles to be emitted from the head at a rate to resupply a tail 100,000,000 miles long, under such circumstances, demands almost unthinkable velocities. On the other hand, if we suppose the general illumination of the tail to be produced from the excitation of a cosmic cloud of dust and gas by streaming electrons from the comet's head, the change in the direction of the tail illumination will take place with the speed of electronic emission, even comparable with that of light. Moreover, sudden changes in the illumination and form of the tail are often observed, notably in the case of Morehouse's comet in 1908, which, very difficult to explain on the basis of the light-pressure theory, appear plausible on the new hypothesis. The fact that faint stars have appeared undimmed by the tails of comets appears to be no surprise on the supposition that the bulk of the material composing the tail was already there in space. The stars would shine through it equally well whether it was illuminated or not. In any event the density of the material must on the average be very low. Calculation in the case of Halley's comet has shown that *on the average* the amount of stuff in 2,000 cubic miles of the tail was not greater than that in a single cubic inch of ordinary air. However, this does not preclude the existence of lumps of matter of considerable density widely scattered through space. Barnard, in studying his many photographs of comets often spoke of sudden changes in the appearance of the tails suggesting encounters with a "resisting

medium." Such abrupt changes might well occur on those relatively rare occasions when a comet would pass into some local aggregation of cosmic cloud in the vicinity of the sun.

If the solar system now were in the midst of a cosmic cloud of indefinite extent, then of course the stars would appear increasingly fainter than they should with increasing distance from the earth. Such does not appear to be the case. If, on the other hand, we suppose our cloud to be more or less a local affair extending perhaps not more than a hundred light years or so, only those stars within that distance would be so affected. The number of such stars is comparatively small. Beyond that distance all stars would be dimmed the same amount so far as any obscuring power of this local cloud is concerned. It has been argued that, since blue light is scattered by small particles much more than red light, the more distant stars should appear redder than the nearer ones, whereas in general we find that the more distant stars are the bluer ones. It is easy to see, however, that the effect would not be a progressive one unless the hypothetical cloud extended to the remotest stars. Furthermore, to produce the selective scattering it would have to be composed of the finest dust powder imaginable. A gathering sea fog dims and ultimately obscures the distant lighthouse without in any way altering its color. The small particles in this case are too big to introduce a selective absorption or scattering. If there were a sufficient number of stars within the limits tentatively set to our local cloud, and the cloud

contained a large enough percentage of the finest pulverized matter, then we might expect to find some tendency for the stars near the boundary of this cloud to appear redder than those closest at hand. Apropos of this delicate test, Professor King of the Harvard Observatory has recently announced that he does find some unmistakable evidence that the nearest stars of a given class are somewhat bluer than similar stars seen at a greater distance. He believes that his results support the circumsolar cloud hypothesis.

While many of the bluest stars are at great distances from the earth, there is nothing against the supposition that these terrifically hot stars would appear actually bluer than they do, were it not for the presence of some amount of selective scattering which reduces the percentage of the light of shorter wave lengths reaching the earth. I would suggest as a further bit of evidence in this direction the well recognized discrepancy between the theoretical temperatures of the stars and temperatures derived from observational data. For many years the temperatures of stars have been determined observationally by measuring the distribution of the light intensity throughout their spectra. According to well-known laws of radiation expressed by Wien and by Planck the wave length of the part of the spectrum showing the maximum intensity of illumination is an index of the temperature of a luminous body. The temperatures of the stars derived in this way are generally lower than those deduced from the modern atomic considerations in accordance with the ionization theory of the Indian physicist, Saha. This

discrepancy can, perhaps, be entirely reconciled if we allow for a small deficiency in the blue light of the spectrum of the hottest and more distant stars caused by the selective scattering from a cosmic dust cloud.

An irrefutable argument for the mere existence of interstellar matter is to be found in the almost universal presence of the dark absorption lines of ionized calcium in the spectra of stars. These lines do not shift about with other lines in a star's spectrum in accordance with Doppler's principle outlined in a previous chapter, but give silent testimony to the existence of vast clouds of calcium lying between us and the distant stars. Eddington in his "Stars and Atoms" estimates that in all space within our galactic system there must be, on the average, one atom of calcium for every cubic inch. While the existence of calcium atoms in interstellar space would readily account for the selective absorption of light as represented by the dark calcium lines, these atoms would not of themselves cause any general dimming in the light of the stars shining through. A general dimming would have to be caused by larger lumps of matter than single atoms. If, however, we have such unmistakable evidence for some of the building blocks of matter permeating all space, does it seem unreasonable to suppose that there should exist aggregations of these building blocks in bundles of sufficient size to cause appreciable obstruction to the light from distant stars?

Again, apropos of this thesis we may do well to note that the stars in general appear to be only about

one-tenth as luminous as Eddington says they should appear on theoretical grounds. This is the equivalent of saying that, as the astronomer measures brightness, the majority of the stars appear about two and a half magnitudes fainter than they should. Calculation shows that, with no allowance for scattering, an obscuration of light of this amount could be produced by opaque particles 1 millimeter in diameter distributed more or less uniformly throughout a cloud 100 light years in diameter with but one such particle to every 140 cubic miles. Even so the density of the hypothetical cloud would be less than one million, million, millionth (6×10^{-19}) that of air, and the total mass would be about that of 200,000 stars the size of the sun. Allowing for scattering, the amount of matter needed to produce the effect would be much less.

Whatever further researches may reveal in regard to this problem, it seems most certain that, in the sun's migrations through the universe, the solar system must often encounter some vast clouds of cosmic matter such as we see so conspicuously silhouetted against the star clouds of the Milky Way. What the effect on the earth may be in such circumstances it is interesting to reflect. If the cloud should be of considerable density it is more than likely that the temperature of the earth would be materially lowered. Observations of solar radiation have shown that in years of great volcanic eruptions the amount of heat received by the earth from the sun has been considerably less than the normal quantity. Notable instances of this occurred in the cases of Krakatao, Pelée, and Katmai.

On each of these occasions the terrific eruptive force of the volcano hurled tons of pulverized dust into the upper atmosphere which did not return to earth for many months. Carried by upper-air currents it was spread in a thin layer around the entire globe. The dust particles acted much as a screen to the radiation of the sun and were undoubtedly responsible for the decreased solar radiation reaching the earth during those years. If such can be the effect of a relatively thin shell of volcanic dust it is more than likely that the passage of the solar system through a cosmic dust cloud would result in lowering the temperature of the earth by several degrees. If such lowered temperature were to persist for any considerable length of time winter snows would cease to melt and an ice sheet of vast extent would gradually form in the otherwise temperate zones. This appears one of the most plausible explanations of the well-known glacial periods of geologic history.

To add zest to this contention we have only to note that the constellation of Orion which is completely enshrouded in nebulosity lies not far from the wake of the sun's motion through space. One of the darkest patches of cosmic fog ever photographed lies just south of the well-known nebula in the sword of Orion. Recent investigations at the Mt. Wilson Observatory indicate that the luminous part of the great nebula itself is rendered visible by the action of the Orion stars upon the neighboring regions of a vast dark cloud. The part of the great nebula so rendered luminous must be as far away as the adjacent stars. This is

PLATE XXIX.—Great nebula in Orion. (*Yerkes Observatory.*)

PLATE XXX.—The Horsehead, dark nebula in the constellation of Orion. (*Mount Wilson Observatory.*)

about 150 light years. The distance may be overestimated, however, as in obtaining such results no allowance has been made for a possible dimming in the brightness of the stars due to any absorption of light by any portion of the nebula itself. Apart from this question, it appears that since the whole region of visible nebulosity covers an area of some twelve hundred square degrees, the distance from the earth to the borders of this great cloud may be but a small fraction of the estimated distance.

It seems more than plausible that at the times of the great ice ages several thousands of years ago the sun may have been in the region of space where existed a cosmic cloud of considerable dimensions. The wide variations in temperature which the earth has undergone for considerable periods in geologic time seem to be more satisfactorily accounted for on such a basis than on the supposition that the sun itself experienced any considerable variation in its output in the last hundred million years. Geologists tell us that the earth at present appears to be emerging from the last glacial epoch and that balmier climates are in store. We might interpret this astronomically by supposing that we are now emerging from the last encounter with any cosmic cloud of appreciable density and are perhaps just clearing the outer reaches of an attenuated region. What lies ahead and how soon the sun may again engulf us in an intraspacial fog only imagination can venture to speculate.

IV

Man Wonders

I grow aware
Of an appalling mystery . . . We, this throng
Of midgets, playing, listening, tense and still,
Are sailing on a midget ball of dust . . .
What does it mean? Oh, God, what can it mean?

—ALFRED NOYES.

CHAPTER XVI

Is There Life on Other Planets?

ONE night in May in 1912—the year is quite important to the incident—a visitor was peering through the great 36-inch telescope of the Lick Observatory. There on the top of Mt. Hamilton he was aloof from the hubbub of the business world. Lights of distant cities at the dark mountain's base twinkled like stars. The telescope was directed at the great globular cluster of stars in the constellation Hercules. At this he gazed. He was awe-struck with this cluster of a hundred thousand suns. It had just been described to him by Dr. Campbell, Director of the Observatory. Long he looked in silence. At length he broke the pause:

"Do you mean, Doctor, that I am looking at a system of suns like ours, and that there are a hundred thousand of them?"

"Quite so, but the stars are many times bigger and brighter than our own sun."

"Can there be any planets going around those suns like the planets in the solar system?"

"It would seem very probable that around some of those suns there should be planetary systems. But of course we could never hope to see them."

"Well, if there are planets there, is it at all possible that some of them may be in a similar condition to the earth, and can support life?"

"It would seem very possible indeed."

"Well, do you think that on any of those planets there could possibly be intelligent beings like ourselves?"

"It would seem quite presumptuous to suppose that such might not be so."

"Well, Sir," he ejaculated, "I don't see that it makes a whole lot of difference whether Roosevelt or Taft gets nominated next month."

I do not suppose that when this enthusiastic visitor came down from the mountain he showed any less interest in politics or in campaign issues. But I have often wondered if he did not have just a little bigger outlook on some subsequent political or industrial problems than he would have had but for that night's experience among the stars.

It is of interest that one question that is asked the astronomer more than any other is: Do you think there is any life on other worlds? I often wonder just what it is in the human make-up that makes this the one persistent question whenever a talk on astronomy directs attention to the stars. Can it be that there is a certain subtle kinship between ourselves and the all but infinite universe in which we seem to play a part? Perhaps one of the most hopeful signs of the universal spirit of man is that he should seek an answer to this question.

Before attempting to answer directly what astronomy can say as to the habitability of other worlds we

had best regard some of those qualities of environment which make possible life on the earth. The bare essentials for biological existence include reasonable temperature, access to water, an atmosphere with oxygen, and adaptation to environment. I am sure we have all heard people dissertate about the marvelously poised qualities of the human frame in the natural order about us. Of course this is no matter of accident. We are what we are because of the world in which we live and the inextricable sifting process of time past. No creature endowed with any radically different qualities from those which we possess could possibly survive on a planet of the earth's make-up. When we talk about the question of life on another world we must think in terms of the essentials of life as we know it. To talk about the existence of life under radically different conditions would be fruitless from the point of view of our meager understanding.

Looking at the physical condition of the other planets within our solar system we find little to encourage us to believe that any life resembling our own could possibly exist on more than two planets besides the earth. I refer to the planets Venus and Mars. The planet Venus is nearly a twin sister to the earth, so far as its size is concerned. It has an appreciable atmosphere and may possibly be in a condition to support some form of life. The greater nearness to the sun would lead us to suppose a much higher temperature than that to which we are accustomed on the earth, but perhaps it would not be intolerable. Astronomers are still somewhat in doubt as to whether or not

the planet rotates upon its axis in a short period of time commensurate with our own day, or whether it rotates only once in its period of revolution about the sun (228 days). The reason for our ignorance of conditions on Venus is largely due to the fact of its proximity to the sun. When nearest the earth and, therefore, in a situation most naturally to reward our scrutiny we find that the illuminated half of the planet is toward the sun and we can barely glimpse it. By the time the planet has moved in its orbit until a considerable amount of its illuminated surface is presented to the earth, it not only has greatly increased its distance from us but is so nearly lost in the sun's rays as to be a difficult object for observation with the telescope. However, recent observations at the Mt. Wilson and Lowell observatories seem to favor the idea that the planet has a day of about the length of ours. Attempts have been made to determine the existence of oxygen in the planet's atmosphere but thus far any spectroscopic evidence has been in the negative.

In the case of Mars the situation is quite different. On account of the eccentricity of its orbit, every fifteen years Mars comes within a distance of 35,000,000 miles of the earth. As astronomical distances go, this is what we call a close approach. Fortunately on these occasions the planet is in a very favorable position in the sky for observation throughout most of the entire night.

On one of these favorable occasions in 1877, Schiaparelli, an Italian astronomer, observed certain fine dark markings on the planet's surface which he termed

"canali." This has been translated into English as "canals," and perhaps is an unfortunate and all too literal translation. However, Schiaparelli's discoveries attracted the attention of certain astronomers, and led them to scrutinize the planet with renewed zest. A pioneer American astronomer, who devoted himself to the eccentricities of this planet, was Percival Lowell. Realizing the great importance of superior climatic conditions for telescopic observation, Lowell selected a site at Flagstaff, Arizona, for an observatory whose paramount purpose should be the investigation of the planet Mars. There he established an observatory on Mars Hill and equipped it with a 24-inch telescope of highest quality. The results of Lowell's researches brought to light many of the canals observed by Schiaparelli, in fact a vast network of fine lines covering the planet in the most artificial-looking manner. At the junctions of many of these lines Lowell reported the existence of dark areas.

The most conspicuous feature on the planet's surface and one which may be seen with any good telescope under favorable conditions is a small, white polar cap. This waxes and wanes with the progress of the Martian seasons. The axis of Mars is inclined to the plane of its orbit very much as is the earth's axis inclined to its orbit. There are, therefore, seasons on Mars which must correspond to our own spring, summer, autumn, and winter. The white polar cap appears largest during the Martian winter season and diminishes as spring comes on, often vanishing altogether during the summer season. With the approach

of autumn and winter the polar cap reappears and attains larger dimensions. Concomitant with the changes of the polar cap, conspicuous changes occur in the network of the so-called canals, many of which are prominent during the summer season, but completely vanish with the advent of winter. Because of the highly artificial appearance of this network of canals, Lowell seriously postulated that they were marks of intelligence. According to his theory, intelligent beings existed on the planet, and because of low water supply they had tapped the chief available source of moisture on the planet, an ice cap. By some gigantic engineering feat, he pictured that they were able to convey water through carefully constructed irrigation ditches to great distances over the planet's surface, in this way making vegetation possible. Many astronomers doubted the existence of water at all on the planet's surface, and even attributed the polar cap to the condensation of carbon dioxide. The work of subsequent years, however, has quite definitely demonstrated the existence of water vapor within the atmosphere of Mars and has lent considerable weight to the ice-cap theory.

One great source of difficulty in supposing the planet to be inhabited has to do with its temperature. Mars, being much farther from the sun than is the earth, receives proportionately less light and heat from the sun itself. Earlier calculations seemed to indicate that the temperature of the planet could not be far from 40° below zero. This literally gave a chill to scientific enthusiasm for the existence of Martians.

Within the last few years new developments in scientific instruments have made possible the construction of delicate thermocouples, devices which, when exposed to heat from a distant source, generate a measurable quantity of electricity. The current so generated is measured by electrical recording instruments of the greatest refinement. In the hands of Coblentz and Lampland at Flagstaff, and Pettit and Nicholson at Mount Wilson, the thermocouple has been applied to measuring the heat radiation from Mars. The results of these researches at the last two near approaches of Mars (1924 and 1926) revealed the fact that, contrary to all previous suppositions, certain regions of the planet's surface attain a temperature of some 50° or 60° F. Thus, life has been found possible so far as temperature is concerned.

Observers at the Lick and Lowell observatories have obtained novel photographs of the planet at the last two oppositions which substantiate the existence of a considerable amount of Martian atmosphere. They made use of special red filters which were successful in delineating details with remarkable contrast. Photography with red light has great penetrating power, and reveals the planet's surface as though it were devoid of atmosphere. Photographing the planet with blue light on the contrary gives an image formed chiefly by the blue rays scattered by the outlying atmospheric particles. Pictures so taken show a generally diffuse globe with no details of surface markings. These experiments indicate that the atmosphere of Mars is quite sufficient to mask details, just as our

own hazy atmosphere so often masks the details of a distant terrestrial landscape, unless the photographer takes pains to employ a yellow or red light filter before the lens of his camera in making the exposure.

Astronomers may never be able to state definitely whether Mars is inhabited or not, but we can say that information as to the habitability of the planet is more promising now than heretofore. We must bear in mind, however, that even if life should exist on our neighboring planet it would be vastly different from anything with which we are acquainted. In spite of similarity with the earth in many essential respects, differences exist of such great magnitude as to make any attempt at picturing definite forms of life there about the wildest speculation.

As to the possible existence of life elsewhere in the universe, an astronomer as such can say but little. It seems almost unthinkable that in a universe of several billion suns there should not evolve here and there, even though rarely, planetary systems not very different from that surrounding our own sun. In such systems around some distant stars there may be now some planet far more like the earth than is the planet Mars. On the grounds of the similarity and unity of matter there is, perhaps, the strongest argument for the universality of life.

CHAPTER XVII

Has Life Any Cosmic Significance?

RECENT progress in science points to a unity in nature never before so objectively appreciated. Everywhere in the universe we find the same kind of matter we have on the earth. Does not this suggest that life itself is a common denominator to all creation? Should we not then expect it to manifest itself whenever and wherever matter in its various forms favors a conducive environment?

Much speculation has been entertained from time to time by the more imaginative thinkers as to the origin of life. Svante Arrhenius, in his "Worlds in the Making," speculates on the transportation of germ-plasmic spores throughout the universe on the waves of light. Since the dawn of the electromagnetic theory of light under Clerk Maxwell radiation has been known theoretically to exert a pressure or repulsive force. In the case of minute particles no bigger than the wave length of light, radiation pressure would actually overcome the gravitational attraction of a luminous body and propel the particles indefinitely into space. Such a repulsive force was actually demonstrated and experimentally measured in this country by Nichols and Hull a quarter of a century ago.

Some scientists have suggested that life-spores were brought to the earth on meteoric particles or cosmic dust. But why not assume that life has originated on the earth, or on any other planet, as the natural expression of a combination of circumstances favorable to its maintenance? The whole story of organic evolution exhibits the origin of species as adaptation to environment. When adaptation is unfavorable, the species will not mature. If a favorable adaptation ceases, the species must vanish. Is the intellectual difficulty any greater to assume life indigenous to a planet than it is to assume it exists elsewhere and is transported thither on the wings of light, or in the electrostatic field of an agglomeration of electrons that make up a meteoric particle?

Subatomic physics is fast uniting the sciences. Astrophysics, physical chemistry, and biophysics are the result. Cell and tissue and metabolistic processes are now being studied as the movements of electrons. The more or less artificial barrier between plant and animal life is fast breaking down through present researches. May not future investigations reveal the organic and the inorganic as intimately associated? There are, and perhaps always will be, those who vehemently protest such an outlook. Their reply to such a thesis is a protest of the emotions: "Life is reduced to pure mechanism, and the soul of man to mechanical operations." I have a certain sympathy for these protesters. But is the picture as bad as it appears? May we not rationalize up as well as down and say that on the contrary that which is highest and noblest in man

permeates in essence the smallest unit of matter? To mechanize the spirit of man is but to spiritualize mechanism. Is this not after all optimism at its best? Is not the thought of unity in the universe the grandest venture of man's mind?

I vividly remember first viewing Pillsbury's films exhibiting the growth of plants and flowers. With almost unbelievable patience he photographed the stages of growth of a plant at intervals of but a few minutes between exposures. He extended the series over a period of weeks and months until he had sensibly a continuous record of growth from seed and bulb to flowering maturity. When these thousands of exposures are run sequentially through the cinema projector one sees in the space of a few minutes changes which required weeks or months for nature to perform. The result is astounding. The sprouting seed exhibits the vivacity of animal behavior. The struggling shoot pushes out and up to overcome the soil's resistance. It turns and writhes with gusts of light and air. It weaves its way about a trellis as though intelligence directed every moment. Suggestive of a consciousness of its ever-changing environment, it turns to meet the rising sun, or droops to sleep when shadows fall. The magic of the Hindu charlatan who grows a mango while you wait is mockery in comparison. The tales of the Arabian Nights are but cartoons of such a spectacle. One may not say that such a picture is not true to life. It is life itself that gave the record. Only the time scale has been distorted. Is not time—the mysterious concept which no philosophy may define—

but the chart on which we plot the events of life? The theory of relativity denies even its reality. Pillsbury has visualized for us a new time scale, that is all. The slowly opening rose now snaps its petals back as though expressing its own spontaneous volition.

We are all quite familiar with slow cinema. We have seen the golf ball leave the driver with a leisureliness that brings merriment to any audience; or if it were putted, we have seen the ball roll at snail's pace across the green and crawl into its hole. Ridiculous, we say. Not so at all, it was just what happened, only we have plotted the event on a lengthened time scale. Suppose we lengthen the scale still more. The quickest movements of the athlete become unperceived for hours. A sufficiently retarded time scale renders him a statuette. The impatient spectator would say there was no movement of eye or muscle, no sign of life; yet the record is there, every change is photographed. We should see the changes if we could be patient to watch long enough.

Geology tells us that, whatever may be the ultimate origin of the earth, through unthinkable but rather definitely measurable epochs, our planet has undergone drastic changes. Earth movements throughout thousands of millions of years have created continents; raised mountain ranges; depressed shore lines; evaporated seas; united and severed, and again united, the Americas. Huge ice sheets crowded southward from Canada, scouring valleys and carving canyons. The ice shrunk, leaving vast moraines, lakes, and roaring torrents. Sedimentation built up plains, and silted

ocean beds. Suppose the cinematographic record of the last half billion years were compressed into the 20-minute showing of a single reel. How the earth would appear to heave and writhe. Its surface wrinkles and straightens, its rocks grow and vanish with unceasing change. Would not some spectator exclaim with uncontrolled wonder: "It's uncanny. It's alive!"

Surface movements quicken. Forests grow and vanish in a moment, and are buried beneath the folding turf. New growths arise. Huge amphibians, pterodactyls, and dinosaurs flash for a moment on the screen and are gone. New species enter and exit. At last man flashes up. Caves give way to more pretentious dwellings. Slow down the picture. Civilizations rise and fall. Turn the reel more and more slowly. At length we find ourselves with the time scale retarded to so slow a measure that we perceive events in what we call our world today. What events are just ahead on the unshown reel no man may tell.

Astronomy above all else impresses us with unthinkable distances and unmeasurable time. Yet it is only by striving to gain some picture of such distances and time that man learns to appreciate something of his position in the cosmic scheme, where a thousand years will not even make a yesterday when they have passed.

Suppose you are reading this paragraph at about eight o'clock of an evening, and that like an Alice in Wonderland you have partaken of a concoction of such strange mixtures that your time sense becomes distorted so that a year's events appear to have oc-

cupied but the space of a minute on your watch. Reflect upon the world's history.

A quarter of an hour ago the World War was started. The fighting was intense, but it was all over, and the Treaty of Versailles signed, inside of five minutes. A half hour ago was the Spanish War. An hour and eight minutes ago, Abraham Lincoln was guiding the destiny of a divided country. It was re-united in four minutes. You had your dinner an hour ago, at seven o'clock. The reconstruction period following the Civil War was over before you finished the *hors d'œuvres*. An hour and a half before, or at five-thirty by your watch, a rather unpopular tea party was being held on board ships in Boston Harbor. In less than two minutes an old bell in Philadelphia cracked, celebrating the first Fourth of July. King George III had irritated some American colonists, and it took fourteen minutes to settle the trouble, organize a new nation, and set up George Washington as the first President.

Look back a bit further into the pageant of history. At three o'clock this afternoon things were not very happy in England. A bit of intolerance was breeding there. An energetic group of young folks decided they did not like the way the tide was setting, so they hired a little ship and went out with the next tide. They sailed across the Atlantic to Plymouth Bay. Now half the population of this country claims its ancestry was aboard that "Mayflower."

At a quarter of one today three Spanish galleons, under the chaperonage of Christopher Columbus, hove

to off the Bahama banks. The great continent lying a hundred miles to the westward was thereupon declared discovered. The continent was named "America," and its inhabitants misnamed "Indians," and the foundations were laid for an independent order of the Knights of Columbus.

At twenty-four minutes past noon, Copernicus was born. In a little over an hour he had his heliocentric theory all worked out. At one thirty-six his celebrated book was published and his career was over. Before three o'clock, Tycho Brahe, Kepler, Galileo, and Newton had all made their contributions, and the planetary theory was established on a sound mathematical basis.

All this forenoon civilization was at an ebb. Rome, which was in the ascendancy yesterday morning, had created an empire by noontime; but it couldn't stand the pressure from the North, and at seven o'clock last night the city was sacked by the Vandals.

At about twelve-thirty yesterday afternoon, a strange character appeared on the east coast of the Mediterranean. He began teaching a philosophy so idealistic and so intimately personal that he was a complete misfit in the society into which he came. Inside of three minutes his antagonists had made away with him. Yet the influence of his life for those brief moments so impressed mankind that the calendars of nations were redated from the birth of that Galilean.

Day before yesterday Egyptian civilization was at its height, and life was thriving along the Nile. A week ago, nomadic tribes roamed about the Mesopotamian

valley, leaving little or no record of civilization. A few months or a year ago, cave men roared over moonlit wastes in the dim dawn of the Homo. A century ago, dinosaurs dominated the heavyweight class of Mesozoic fame. But we must go back a thousand years in our shortened time scale for the earliest forms of life, and a million years before for the beginning of the earth as a planet. Meanwhile, then as now, and as it shall be for unthinkable time to come, gigantic spiral nebulae whirl in endless rounds their atomlike stars in the genesis of other universes. What will be happening on the earth a few months hence, or even a few weeks? Greece and Rome yesterday, Babylon and Egypt the day before, what shall be tomorrow and the day after? Man as a species is yet very young. Will he survive, or will his own civilization create an environment to which biologically he may not be adapted? Will he continue to employ his genius for malicious contrivances that a few hours hence shall destroy the very civilization which his ingenuity has built? However hopeful and optimistic we may be for the future of the race, physically man's days must be numbered. Astronomically considered, life is but an incident in the history of a planet. Yet associated with that life in its more conscious forms is an inquiring intelligence that suggests its origin.

Are we ourselves perhaps a limited expression of an all-pervading consciousness? May some spark of such consciousness exist potentially with the smallest units of matter? Electrons, identical so far as we can tell, assemble into different aggregations and produce

atoms of widely differing characteristics. Atoms of various elements, in turn, combine to make molecules of substances having properties vastly different from the qualities of the elements themselves. Is it that these same units of which worlds are made are the building blocks of mind? Is the unification of all the lesser units into some super-universe the supreme order of intelligence? If this be so we are ourselves a part of such intelligence. Such a conception is not at variance with the thought of many creative minds in the realms of philosophy, of religion, and of science.

Chamberlin, in his "Origin of the Earth," voices his own speculations in regard to this. He closes his volume in the following words:

> It is our personal view that what we conveniently regard as merely material is at the same time spiritual, that what we try to reduce to the mechanistic is at the same time volitional; but whether that be so or not the emergence of what we call the living from the inorganic and the emergence of what we call the psychic from the physiologic, were at once the transcendent and the transcendental features of the earth's evolution.

Eddington in his "Nature of the Physical World," while stressing the abstract conception of the atom in modern physics, says:

> Why not then attach it to something of a spiritual nature of which a prominent characteristic is thought. It seems rather silly to prefer to attach it to something of a so-called "concrete" nature inconsistent with thought and then to wonder where the thought comes from.

What may be the exacting conditions required for life to develop to a stage of intelligence such as we

ascribe to man, science may never be able to discover. To attempt to maintain that such life exists only on this earth seems the height of absurdity. On some hypothetical planet revolving about some distant sun there may very well be a race of beings much like ourselves, perhaps far more intelligent. With telescopes grander than any we have constructed they may penetrate into the deepest recesses of their sky, map stars and nebulae, and in sober reflection wonder as we wonder: "Can there be intelligent life anywhere else in the universe?"

CHAPTER XVIII

Has Science Displaced Religion?

On one occasion a fellow traveler engaged me in a talk about the stars. I answered some of his questions about the distances to some of the more conspicuous stars and told him how big they were as compared with our sun and the earth. He listened intently for a few minutes and then interrupted, "Doctor, have you any religion?" He seemed anxious to go on, so I let him proceed.

"What kind of a God can a man pray to, in a universe like this? I was brought up in the strictest type of a religious family, but I simply cannot believe the creed of any church, now."

Another interjected: "There are not any astronomers who believe in a Deity, or any hereafter, are there?"

I mention these typical incidents to illustrate for the moment how talking about astronomy so frequently leads to questions of religion.

It is inevitable that a man's reflection on such a universe as we have pictured should react upon his life philosophy. Considering the millions of years in which man has been adapting himself biologically, the transition of his thinking in the last few centuries

has been extraordinarily rapid. The demand for readjustment of ideas to keep pace with the progress of science was perhaps never more acute than now. We have seen the flat earth and its overarching sky of yesterday metamorphosed into a stellar system of such dimensions in time and space that even the astronomer is helpless in his attempt to conceive adequately of its proportions.

The life of the individual itself seems to be so insignificant in such a scheme that the doctrines of astronomy often tend to pessimism. Such reactions have frequently been displayed in literature. Theodore Dreiser, in a recently published credo, says:

> I can make no comment on my work or my life that holds either interest or import for me. Nor can I imagine any explanation or interpretation of any life, my own included, that would be either true—or important, if true. Life is to me too much a welter and play of inscrutable forces to permit, in my case at least, any significant comment. One may paint for one's own entertainment, and that of others—perhaps. As I see him the utterly infinitesimal individual weaves among the mysteries a floss-like and wholly meaningless course—if course it be. In short I catch no meaning from all I have seen, and pass quite as I came, confused and dismayed.—From *The Bookman*, September, 1928.

If you have read thus far, have candidly faced the facts of the universe, and experienced none of such questionings, or if you have been reared in the faith of the fathers adapted to a pre-Dantean cosmology and are still quite contented with a Nicean theology, then I beg of you read no further into this chapter, for there is nothing further in it for you. Close the

book and recite a stanza of the old hymn of Addison's over which there can be no contention:

> The spacious firmament on high
> With all the blue etheral sky
> And spangled heavens, a nightly frame,
> Doth their Original proclaim.

Or perhaps you think of another class who care nothing at all for mystical speculations, regard all such questions as of even less than academic interest, and graciously leave them for other temperaments to wrangle about. If so, then I will close the book for them by telling you of one of my students of whom they remind me. Answering a question on an examination paper regarding stellar evolution, he vividly portrayed the life history of a star. Arriving at the "blowing up" stage, â la Jeans' hypothesis, he added with characteristic sophomorism: "but before this happens the earth will have come to its end, and all life will have vanished together with the astronomers who so worry about these things."

But if you have survived the paragraphs above and are still reading, I must assume you belong to a third and rather large group of individuals who, taking the facts of science for what they are, nevertheless strive for some picture of life that will give it meaning. Realizing that the more conventional forms of religion have not kept pace with the rapid strides of scientific thinking, you have perhaps come to wonder what sort of religion, if any, can ultimately survive, or is all religious thinking to be relegated to the past along

with fables, superstitions, and other folklore. It is easy enough to criticize destructively the faith of our fathers, or to damn it with faint praise. I can but hope, however, that I may suggest something more constructive which, though it may not point the way to any ultimately satisfactory philosophy, may present certain reflections that shall encourage thinking toward a somewhat more cheerful outlook than the one represented in my quotation from Mr. Dreiser.

While it may appear that science is all-inclusive in its searching from the microcosm to the macrocosm, it is worthwhile to consider that physical science has its limitations. The new principle of indeterminism announced by Heisenberg in 1927 has struck a note of uncertainty in our methods of divining the ultimate nature of matter. As a voice ex-cathedra it seems to have spoken: "Thus far shalt thou go and no further." The very tools of the physicist are beginning to appear inherently too cumbersome to lay bare the hiddenmost secrets of the electron. If we would trace its movements with great accuracy we must be content not to know just where it is. If we would know just where it is, we must be content not to know just how it moves. Strange dilemma, you say. So it is. At best our most exact measurements are but approximations, and the most fundamental laws of science can ever be but approximations to the truth.

While it appears that there is no corner of space into which science may not penetrate, it is somewhat surprising when we consider the ways in which the scientist is really limited in his pursuit of knowledge.

Not only have we the limitations inherent in our methods of measurement, but we are greatly circumscribed with the limitations of our own make-up. Such limitations are both physiological and mental. Our points of contact, with the exterior world in which we live are limited by our senses of perception. To be sure we have invented all sorts of mechanical contrivances to extend the normal range of our senses such as the microscope and the microphone, the telescope and the telephone. We have invented the fluoroscope and the photographic plate to bring into the region of visibility the actions of radiant energy in the form of X-rays, and by means of such devices we have tracked the very paths of the invisible electrons themselves. We have invented the vacuum tube and the amplifier to transform electrical frequencies into sound waves audible to the normal ear. But we may never know what information may be broadcast from the stars in a form not detectable by any of our physiological senses. Man can boast of but five senses. The chemist in his laboratory often utilizes all of these in ascertaining the nature of some substance or solution. The astronomer on the other hand must be content with examining his specimens at long range. Whatever data he gathers from the distant stars must come to him on the wings of light. Man is 80 per cent handicapped in attacking the problem of the structure of the sidereal universe. Yet slowly the information grows. Bit by bit fragments of knowledge build a universe of increasing significance, the full meaning of which we shall doubtless never grasp.

I sometimes think that solving the riddle of the universe, as we come in contact with it in a physical way, is much like attempting the solution of a gigantic picture puzzle. There are so many pieces that no one individual and no generation of individuals can expect to put them all together. Little by little scientists have discovered here and there certain resemblances in the contours of some of the pieces. They have assembled many of them into little patches with suggestive meaning. The patches grow. A picture forms. Here and there in the picture trees and flowers appear, a bit of gorgeous sky, and open sea. It seems at times as though man caught a glimpse of the larger picture of which this patchwork is a part. Then as has so often happened in the history of science, progress is stalled. Some very recalcitrant pieces refuse to fit in. Trees and flowers do not join with sky and sea. Perhaps what was thought to be bits of sky and cloud are but inverted images in a pool of water. Now and then there arises some master mind, who looking over the work of his predecessors begins to see some larger plan and purpose in the picture than has been dreamed by all the puzzle workers who went before. To reconstruct on a new basis, however, entails the demolition of much that it may have taken years to arrange. Many apparently well-formed groups must be disintegrated. Reconstruction begins along the lines of some newly projected theory. As some of the older patchwork fits in on the new basis, progress begins again. Former elements in the framework may be restored with new significance. Such is the story of the

progress of science. But at best, even should we get all the pieces together, we shall have but a flat picture—not even the three-dimensional world in reality. Accurate so far as it goes, it is a very restricted portrayal of the thing behind the representation. Thus do we begin to sense limitations of science other than mechanical handicaps.

We have seen something of the difficulties of the cosmogonist who has tried to give us a picture of evolving worlds. We have traced the life history of stars from large, dull red bodies to white-hot suns, and back to dull red stars again; but we cannot think of a time before which nothing happened, nor can we think of a time beyond which something may not still happen. Such are the limitations of man's mind. Science can deal only with material things; its conceptions and its laws are based on things which we can weigh and measure. As to what was before matter, the scientist has no answer, for he must start with matter before scientific reasoning or experimentation can begin. According to present astrophysical theories, the stars are actually radiating away their mass and their energy. Is the universe losing weight thereby? Will the time come when all the matter in the universe will have radiated itself away? If so, science can penetrate no further, for it has no longer any substance with which it can deal. According to some scientists radiated energy will perhaps gather itself together again into matter and we shall have a universe re-created. If such a process is possible, then it should now be going on, and we have one vast ebb and flow of

matter and energy through endless time—a self-perpetuating universe. To speak of the beginning and the end of such a universe is quite impossible.

Picture the whole scheme of things which we may call a space-time continuum as an unending circle in space, its rim touching the realm of our consciousness in but one small region of contact. Here the circle momentarily traces a chalk mark on the blackboard of our three-dimensional world. Here the grains of chalk, surveyed by man's inventive genius, form a brief line in the region of our experience. Along this tangent line we arrange the events of what we call the universe. We see a sequence in the chalk dust particles. They form a little puzzle picture, many parts of which fit into each other with some significance, we think. As we look toward one end of this material line, which we label the beginning, our mental picture grows fuzzy. We find it difficult to see what went before. Tracing events to the other end of the line we find the dust particles thinning out. We grow aware of the fact that our consciousness cannot follow. This is where the chalk line leaves the blackboard to describe a circle in space representing a void of knowledge for which we have no powers of perception. Whatever the universe is, it comes into the consciousness of a physical scientist only as it touches his three-dimensional world. His ability to reason to where consciousness becomes hazy suggests that man's mind all but leaps a little way from the world of the material into another world not restricted by matter and familiar dimensions.

Yet, we all share in experiences not expressible in terms of things we can weigh and measure. We live in a world of beauty, a world of motives, and a world of values based on standards other than the metric system. The scientist may analyze the pigments on the canvas of a Rembrandt; he may give the coordinates of each object represented, and the wave lengths corresponding to the colors. But such a description can never reveal the soul of a Rembrandt which the artist may see. A scientific description of a book may give its mass and volume and its chemical constitution; it might even include the formula for all the permutations of the twenty-six letters of the alphabet represented by the subject matter within. But no physical or mathematical description of a book can distinguish the difference between the Bible and John Erskine, or Shakespeare and Milt Gross. As long as man continues to have an appreciation for those qualities which make for art, for literature, and for ideals, he must ever find much of his satisfaction of living in the subtler realm of experience back of the material universe which no science can fully describe, and no philosophy of materialism can completely satisfy. It is in this realm that for want of a better terminology the word religion has meaning.

To say that science conflicts with religion is to say that Leonardo's practical knowledge of pigments was inconsistent with his conception of the Last Supper, or that Michelangelo's technical knowledge of materials interfered with his creation of St. Peter's. On the other hand, one who has not felt something of a mental strain

in the readjustment of ideas brought about by the scientific conception of the universe has probably done little thinking in the borderlands of knowledge. It is inevitable that the idealistic creations of religion should become entwined about materialistic conceptions of the stars. And with a change in ideas of the material universe there must inevitably follow a change in religious thinking. Reconstruction in science sooner or later entails reconstruction in theology. Nothing can be more disastrous to honesty of thought than to try to segregate scientific and religious ideas into water-tight compartments, and to draw upon one or the other in turn as the occasion demands. No normal mind can be consistently happy with ideas sadly at variance with one another and make no attempt at progressive thinking.

For one to suppose, however, that to accept the latest revelations of science means the decadence of things most worthwhile is to misjudge completely the purpose of scientific endeavor. Science and religion, when rightly scanned give supplementary views to a picture of life, vastly deficient when looked at from either standpoint alone. To abandon all cognizance of religion, because of scientific inconsistencies with certain preconceived notions, is as foolish as no longer to recognize gravity, because Einstein has shown that all gravitational forces are illusory, and that the laws of falling bodies may be explained as an acceleration of coordinates. Any philosophy of life which tends to the enjoyment of one's natural environment must take into account the revelations of both science and reli-

gion, and synthesize them into a single body of knowledge which for the individual shall have the most significant meaning.

If any one reads pessimism into the inexorableness of natural law, let him reflect that law and order are suggestive of intelligence and purpose. Without such law and order the cosmos would be chaos, and we should be the victims of caprice and magic. If any one is disheartened because of man's seemingly insignificant place in the universe, let him take courage from the declaration of the Relativists that all dimensions are purely relative and that space and time have no absolute significance. When H. G. Wells selected his six greatest men in history we did not find that their relative physical dimensions entered into his choice, nor do we discredit his selection on that account. It is as absurd to belittle man's possibilities because Antares is a million million times as big as the earth.

If one were to seek some mental picture of man physically that would appear to enhance his place in the category of dimension one might well reflect that as to size he occupies a place about midway between the smallest conceived element of matter, the electron, and the diameter of the whole solar system. Personally I see little consolation in this sort of contention.

What appears to me far more significant, so far as man's place in the universe is concerned, is the thought of the unity of nature; that in the protoplasm of each individual are the same elements of which the stars are made, and associated with that protoplasm is the ability to look into the starlit sky and conceive an all

but unending universe. Into this world of mystery, for a little while, man comes to play his part. How he plays, I fancy, depends quite as much upon his religion as upon his science.

At the foundation of science is the principle that the universe is orderly. The belief that this expression of order is the expression of a superior intelligence, an ultimate Personality, is a premise of all religion. It is exhibited in the totem worship of primitive man, the polytheism of the Greeks, and the monotheistic conceptions of the Hebraic Yahweh, the Moslem Allah, and the Christian God. As the correctness of assumptions in science becomes substantiated through the consistency of subsequent experiments, so in religion the vindication of faith comes in the test of subsequent experience based on such faith. Many of the tentative hypotheses of science trace their origin to an intuition not unlike the intuitions of faith. But we cannot expect science to prove the premises of religion. Observations of the weight and position of material things do not prove or disprove nonmaterial realities. The existence of great personalities such as Socrates, Buddha, Jesus, and Lincoln, afford better evidence for the existence of a Master Personality than any laboratory experiments can offer. Water does not rise above its level, nor a personality above its Source.

Within certain limits science can mold and has molded man's conceptions of Deity. One who has come to appreciate something of the revelations of modern astronomy can hardly contemplate God as a deistic bogy or a capricious worker of magic, nor

regard him longer as a dispenser of favoritism to the holder of any specific creed. "He maketh his sun to shine on the evil and the good, and his rain to fall on the just and on the unjust." The exhibition of extraordinary phenomena may for a time defy scientific explanation. Of course, unknown laws may introduce effects unpredictable on the basis of any known law. But that persistent clinging to the belief of some sort of "miracle" where the law of cause and effect does not apply is due to a gross misunderstanding of science on the one hand and religion on the other. It is the lurking of the *deus ex machina* idea of Deity, both unscientific and unchristian. Those who regard Creation as the continued expression of a Divine Presence can scarcely take satisfaction in thinking of the universe as a once perfect but now abandoned machine, the operation of which may be momentarily disorganized for a display of "miracle" to satisfy the unbeliever that an absentee God looks in now and then on a forgotten régime.

As science has changed conceptions of Deity it has likewise called for a reinterpretation of the books of religion. One no longer thinks of teaching astronomy or geology from the book of Genesis. In the seventeenth century Galileo contended that the Bible was not written to show men how the heavens go, but to show men how to go to Heaven. Such a thesis was poor defence against medieval dogma. The day is past when it is worthwhile to try to distort Biblical phraseology to reconcile Semitic traditions with modern science. Why not take the Bible for what it is,

an extraordinary collection of the literature of a religious people, containing something of history, poetry, and philosophy, but little of science? Is it any less a source of inspiration to read the Scripture as the record of a progressive revelation of God to man, than as a dictated tablet sprung full grown like Athena from the head of Zeus? How much more pregnant with meaning does the Bible become to one who follows the growing conception of God from the anthropomorphic Elohim of Genesis, through the patriarchal Yahweh of the nomadic Hebrews, the tribal king of Israel, to the conception of the universal Spirit shared by the individual as taught by Jesus.

In the light of such changed conceptions of religion as the contributions of science have brought about, we see no longer the sky as a finished firmament, a material curtain hiding us from the Divine Creator now rested from his labors, but rather as a universe of such dimensions and splendor as transcends the imagination. The finished sky of primitive religions becomes the workshop of an unending creation. Man, insignificant as he is dimensionally, becomes associated with, and a part of, such a system, vitally conscious of his environment and yet daring to think his acts are of lasting consequence and his momentary presence a part of a Supreme Plan.

It is not without significance that many of the eminent men of science have been devout followers of religion. Among such may be mentioned Galileo, Newton, Faraday, Kelvin, and Pasteur. Today there seems to be a slow but growing reaction to the material-

stic philosophy of a generation ago. Professor Conklin of Princeton declares, as a biologist, that there is nothing in the evolution of animal behavior inconsistent with an ultimate purpose. Professor Russell of the same institution, speaking for astronomy, said in an interview for the *New York Times*, "Our fathers saw in mountain and valley the six days' work of a master craftsman. We see the operation of a Power so patient that not a mere thousand, but a million, years are but as one day in the accomplishment of its design . . . God never fails to surpass our human imaginations, and, if we are to believe in the kind of a God who alone is credible in these days of ever partial knowledge of His works, we can safely trust such a God to provide for us some future which goes beyond our dreams." Dr. R. A. Millikan, of California, who first isolated the electron, and now believes he has discovered a source for the recreation of matter from cosmic rays, closes his book on "Science and Life" with the following paragraph:

> If there be a man who does not believe either through the promptings of his religious faith or through the objective evidence which the evolutionary history of the world offers, in a progressive revelation of God to man, if there be a man, who in neither of these two ways has come to feel that there is a meaning to and a purpose for existence; if there be such thorough-going pessimism in this world, then may I and mine be kept as far as possible from contact with it. If the beauty, the meaning, and the purpose of this life as revealed by both science and religion are all a dream, then let me dream on forever.

A little while ago I stood in the museum at Cairo looking at the mummy of the supposed Pharaoh of the Exodus. Two sightseers strolled by. Glancing at the

mummy, one seized the occasion to remark on the absurdity of the idea of immortality.

The dogmatic character of the assertion made me say to myself: "Are you so sure?" Too many times have scientists been deceived by the physical appearances of things in the material universe to care to make dogmatic statements in a realm all unknown. Golden streets and tormenting fires have too long colored ideas of the persistence of life to lead to much profitable thinking of nonspacial possibilities. Now that physical science has made impossible a medieval cosmology, and has reduced space and time to a rather visionary framework, perhaps some future psychical science shall yet evolve, that shall discover that Mind after all is the one persisting reality.

It is inevitable that the study of astronomy should make impossible the retention of certain theological conceptions of yesterday. Religious ideas must grow and expand with the maturing of the race as they do with the maturing of the individual. I hesitate to think that any vital religion shall ever ultimately suffer through the patient and persisting searchings of science in the acquisition of truth. Whatever his philosophy of life may be, every scientist is an eager explorer into fields unknown. Like Merlin, in the days of King Arthur, he pushes fearlessly on over many a rugged trail in the pursuit of each gleam that may lead to knowledge. Allured by the fascination of that which evades his grasp, he will seek, and who shall say he may not find something of even more vital significance than that yet revealed in atoms or stars?

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